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INFRARED HORIZON DEFINITION

A STATE-OF-THE-ART REPORT

by Raymond J. Kirk, Bruce F. Watson, Edward M. Brooks, and Robert O'B. Carpenter

Prepared by
HONEYWELL INC.
Minneapolis, Minn.
for Langley Research Center

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FOREWORD

This report documents the first phase of An Analytical and Conceptual Design Study for an Earth Coverage Infrared Horizon Definition Study performed under National Aeronautics and Space Administration Contract NAS 1-6010 for Langley Research Center.

This study provides for delineation of the experimental data required to define the infrared horizon on a global basis and for all time periods. Once defined, a number of flight techniques are evaluated to collect the experimental data required. The study includes assessment of the factors which affect the infrared horizon through statistical examination of a large body of meteorological information and the development of a state-of-the-art infrared horizon simulation.

The contractual effort was divided into numerous subtasks which are listed as follows:

Infrared Horizon Definition - A State-of-the-Art Report

Derivation of a Meteorological Body of Data Covering the Northern Hemisphere in the Longitude Region Between 60°W and 160°W from March 1964 through February 1965

The Synthesis of 15μ Infrared Horizon Radiance Profiles from meteorological Data Inputs

The Analysis of 15μ Infrared Horizon Radiance Profile Variations Over a Range of Meteorological, Geographical, and Seasonal Conditions

Derivation and Statistical Comparison of Various Analytical Techniques Which Define the Location of Reference Horizons in the Earth's Horizon Radiance Profile

The 15μ Infrared Horizon Radiance Profile Temporal, Spatial, and Statistical Sampling Requirements for a Global Measurement Program

Evaluation of Several Mission Approaches for Use in Defining Experimentally the Earth's 15μ Infrared Horizon

Evaluation of the Apollo Applications Program Missions for Use in an Earth Coverage Horizon Measurement Program in the 15μ Spectral Region

Computer Program for Synthesis of 15μ Infrared Horizon Radiance Profiles

Compilation of Computer Programs for a Horizon Definition Study

Compilation of Atmospheric Profiles and Synthesized 15μ Infrared Horizon Radiance Profiles Covering the Northern Hemisphere in the Longitude Region Between 60°W and 160°W from March 1964 through February 1965 - Part I

Compilation of Atmospheric Profiles and Synthesized 15μ Infrared Horizon Radiance Profiles Covering the Northern Hemisphere in the Longitude Region Between 60°W and 160°W from March 1964 through February 1965 - Part II

Horizon Definition Study Summary - Part I

Honeywell Inc. Systems and Research Division, performed this study program under the technical direction of Mr. L. G. Larson. The program was conducted during the period 28 March 1966 through 10 October 1966.

The study results from the first five subtasks listed previously are of considerable interest and warrant wide distribution to the scientific community. It is anticipated that the results of the last eight subtasks are of limited interest to the general scientific community; therefore, distribution is provided to U. S. Government Agencies only.

Results and conclusions of many theoretical and experimental groups are presented in this report. This information was obtained from the literature in the field, government reports, and personal communications. Acknowledgement is given to the many companies and individuals which supplied information and data.

Gratitude is extended to NASA/Langley Research Center for their technical guidance, under the program technical direction of Mr. L. Keafer and direct assistance from Messrs. J. Dodgen, R. Davis and H. Curfman, as well as the many people within their organization.

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SUMMARY

The requirement for definition of the Earth's horizon develops from the need for improved attitude reference in space vehicles. It appears that horizon sensors, operating on the Earth's infrared horizon, can provide an accurate, lightweight, and reliable reference system if the horizon anomalies can be ascertained and shown to be systematic in nature to allow removal of errors for the sensor by calibration. Delineation of an effective Earth horizon definition study demands an extensive examination of present knowledge and theories regarding the Earth's radiance characteristics, techniques for analysis of radiance profile variations, and performance of radiance detector equipment. These areas were examined in depth and this report presents a comprehensive collection of this knowledge. The past activities examined include both theoretical and experimental programs. Within the theoretical area, studies of meteorology, atmospheric physics, and horizon profile modeling and synthesis were analyzed to ascertain their relative effects on horizon definition. Results of past experimental programs were reviewed to determine the most stable region of operation within the infrared spectrum. Factors which affect the horizon profile were examined to separate the systematic from the non-systematic. Each of the horizon uncertainties are then available for use in synthesizing profiles to ensure proper profile construction.

Due to the lack of sufficient experimental radiance data, an examination of the basic meteorological factors contributing to the horizon radiance profile was conducted to allow synthesis of radiance profiles. General characteristics of the atmosphere and techniques for modeling or sampling it were examined. Special atmospheric conditions which could cause variations in the 15 micron horizon profile including concentration variations of water vapor, ozone, carbon dioxide, cloud conditions, and thermal variations are described in detail.

Theoretical horizon radiance profiles have been synthesized from the basic meteorological factors by many investigators using widely varying assumptions and input data. This work has been examined as it relates to techniques for computing horizon radiance profiles from atmospheric temperature profiles. Effects on the radiance profiles of varying transmissivity data, atmospheric

refraction, Doppler broadening, and absence of local thermodynamic equilibrium were also examined to ensure that complete knowledge of their effects are available for profile synthesis. Variations in the radiance profiles as a function of temperature, clouds, atmospheric circulations, spatial and temporal parameters, and wavelengths were also assessed to ascertain their relative effects on profile synthesis.

The results and conclusions from past experimental Earth radiance measurement programs applicable to horizon definition in the 14 to 16 micron spectral region were analyzed for applicability to present horizon definition activity. Reviewed were the IRATE, X-15, D-61, Kodak, Tiros, and Nimbus programs along with several balloon radiance measurement programs. Documentation of the flight performance of horizon sensor equipment and techniques for improving sensor accuracy is described to supplement earlier horizon sensor state-of-the-art performance data.

The experimental horizon radiance measurement programs to date have each provided valuable information about the Earth's horizon. However, for purposes of horizon definition in the 15 micron region, each program has been lacking in one or more aspects such as spatial coverage, temporal coverage, spectral resolution, spatial positioning, or field of view. All of these aspects must be considered to develop a horizon measurement program to adequately define the Earth's horizon; these aspects were examined and presented to assist the reader in assessing the overall horizon definition problem.

INTRODUCTION

Although horizon sensors for vehicle guidance and control have been in existence since 1958 and are used on the majority of orbital space vehicles, the state-of-the-art in their design has been limited because many infrared characteristics of the Earth's radiance profile are not well known. These characteristics must be accurately determined in order to realize the ultimate design and maximum accuracy of horizon sensors. Given a comprehensive knowledge of the horizon profile, an optimum sensor mechanization can be designed by incorporating signal processing logic with optical and electronic filtering, electronic compensation, and computer modeling techniques.

Theoretical analyses and evidence from several previously conducted experimental programs have indicated the carbon dioxide absorption band around 15 microns (u) provides the most promise for infrared horizon sensing. The purpose of this report is to compile and summarize the key elements of past work and present the state-of-the-art of Earth horizon definition in the 15 u spectral region.

Due to the limitations in empirical data on the CO_2 horizon, the state-of-the-art in horizon definition is predominantly theoretical work. Recent experiments by the Langley Research Center and Air Force Cambridge Research Laboratories have significantly improved the knowledge of the characteristics of the horizon through high resolution radiometric measurements but data reflecting horizon definition over a large space and time domain covering the surface of the Earth remains to be completed before the effects of geographical location, seasonal and diurnal variations, meteorological and severe dust conditions, gross geomorphological features, and solar phenomena are to be evaluated. Furthermore, the measurements must be made in sufficient quantity to establish a high level of statistical confidence.

The theoretical work on horizon definition involves analysis of the explicit factors which affect the radiance such as atmospheric temperature and pressure, and implicit factors such as latitude, longitude, time, and meteorological variables. Implicit factors are those which affect the infrared radiation from the Earth's horizon through their respective effects on the direct explicit factors. Modeling techniques have served to provide a better understanding of horizon variations and the physical relationship between atmospheric variables and the infrared emission from the Earth's horizon.

A state-of-the-art report, "Infrared Horizon Sensors," Duncan, et al., University of Michigan, 1965, summarizes the present state-of-development of horizon sensing hardware and associated errors; updating of that work is included in this report. However, this report deals primarily with the problem of horizon definition and measurement rather than the hardware instrumentation. Treated as an entity, these two reports provide for a complete background and the state-of-the-art in horizon sensors and horizon definition.

This report summarizes the state-of-the-art of theoretical and experimental work for infrared horizon definition, including a discussion of meteorology and its implications in radiance profile computations. Techniques for radiance profile modeling, validity of assumptions, and approaches used by previous investigators are described for comparative purposes and justification of present techniques. Descriptions of the systems and results of prior Earth radiance measurement programs and their applicability to horizon definition in the 15 micron spectral region also is given to indicate the relationship between past theoretical and experimental work. Since this report presents a synopsis of past effort, a complete bibliography of all pertinent work was prepared to allow analysis in greater depth.

The results of the compilation of all past theoretical and experiment effort in horizon definition has a significant bearing on developing an understanding of the problem and provides the framework for formulating a complete program approach for definition of the Earth's infrared horizon.

METEOROLOGICAL INPUTS FOR HORIZON PROFILE SYNTHESIS

INTRODUCTION

The infrared horizon profile of the Earth depends on the vertical distribution of temperature and the absorbing constituents of the atmosphere. To analyze variations in the profile, it is presently necessary to generate horizon radiance profiles from meteorological data, since sufficient measurements directly on the horizon are not available. Variations in the input data then appear in the resulting profiles. Meteorological inputs for radiance profile calculations in the 15 μ CO_2 region are atmospheric (temperature, pressure, height) profiles; special anomalies, such as clouds; and composition of the atmosphere.

One reason for choosing a carbon dioxide band for horizon definition is that the carbon dioxide mixing ratio in the atmosphere is relatively constant compared with other possible gaseous absorbers, such as water vapor or ozone. Thus, the time and space variability of the radiance profile due to variations in atmospheric carbon dioxide can be expected to be minimal. Another reason for choosing the 15 μ carbon dioxide band is that this is a rather strong absorption band. Thus, the outgoing radiation in this band will originate mainly from relatively high levels in the atmosphere, rather than at the surface or in the troposphere. This reduces the effects of large variations in surface temperature and, more importantly, the effects of tropospheric cloudiness on the outgoing radiation.

This section summarizes the state of the art of meteorological data and measurement techniques for use in generation of Earth horizon radiance profiles in the 15 μ CO_2 spectral region. General characteristics of the Earth's atmosphere are described. Improvements in modeling of the atmosphere and the value of the model atmospheres for radiance profile computation are discussed. Generation of a set of sample atmospheric profiles for analyzing radiance profile variations is outlined. Special atmospheric effects, such as clouds, stratospheric warmings, etc. can cause significant variations in the radiance profile. Although the carbon dioxide concentration in the atmosphere is generally assumed to be constant for radiative transfer calculations, there are small space and time variations. Since the horizon radiance profile in the 15 μ band depends upon the CO_2 concentration, measurements on the atmospheric CO_2 concentration are reviewed.

ATMOSPHERES

THE REAL ATMOSPHERE

Parameters

Behaving very nearly as a perfect gas, the atmosphere of the planet Earth can be defined in terms of five parameters. These parameters are pressure, temperature, density, molecular weight, and composition. These parameters may be related to each other by the equation of state for a perfect gas.

$$\rho = \frac{M}{R^*} \times \frac{P}{T} \tag{1}$$

where ρ is the density, P the pressure, T the temperature, R^* the universal gas constant, and M, the mean molecular weight, which is a function of composition.

In addition to R^*, M may be regarded as a constant, at least to an altitude of about 90 kilometers (ref. 1). Above that altitude, where dissociation and diffusive separation occurs in the atmosphere, M can no longer be regarded as a constant.

Atmospheric pressure change may be related to altitude change in the atmosphere by the relation

$$dP = -\rho g \, dz \tag{2}$$

where g is the acceleration of gravity and z is altitude. This equation is known as the hydrostatic equation. It will be noted that one may uniquely determine the pressure knowing altitude and density, or the altitude knowing density and pressure. The hydrostatic equation is actually valid only for a static atmosphere, air motion aloft will cause departures from the relation. The error is seldom serious, except in regions of extreme air motion.

Combining Equations (1) and (2) the barometric equation

$$P = P_o \left(\exp - \int_o^z \frac{Mg(z)}{R^* T(z)} \, dz \right) \tag{3}$$

is obtained showing that the pressure is uniquely determined also by knowing temperature and altitude. Again this equation is only true for hydrostatic equilibrium.

In meteorology, the commonly used units of the above are density, ρ, in gms/cubic cm; pressure, P, in millibars; temperature, T, in degrees Kelvin (but degrees Celsius for chart plotting), and g, the acceleration due to gravity in centimeters per second per second.

Other parameters, which are not defining parameters, include specific weight, pressure scale height, density scale height, number density, mean air particle speed, mean free path, collision frequency, mole volume, the coefficient of thermal viscosity, kinematic viscosity, and the speed of sound. More on these parameters, as well as the defining parameters, appears in the subsection on standard atmosphere.

Atmosphere of the Planet Earth

Gas content. -- The atmosphere of Earth is a mixture of gases in varying amounts. These gases are components of the "gas" known as air. At present, only one gas, carbon dioxide, (CO_2) is changing its average concentration in significant amounts. Two other gases, water vapor and ozone, though relatively constant in average concentration on the order of at least decades, are extremely variable with respect to time and space.

In the higher atmosphere, the relative ratio of gases to each other may be changing appreciably at present because of the constant injection of constituents from rocket fuel as a result of the space efforts of the United States and the Soviet Union. Reliable measurement of high-altitude gases was not possible before the advent of the rocket, but it is to be noted that contamination of the high atmosphere is not preventable if it is desired to deliver sensors to those regions. At the present time, this contamination is insignificant for horizon definition to altitudes of 90 km.

Because water vapor is so variable, it is usually left out of tables of the relative amounts of gases comprising the atmosphere. Table 1 shows the relative amount of the various gases comprising the Earth's air at sea level.

Solid and liquid content. -- In addition to the gas content, the atmosphere contains liquids and solids.

Solids are present in the form of minute particles of "dust", vegetative material, and salt which are injected into the air, but which fall out slowly because of their small size.

Liquid is present as a result of the condensation of water vapor. Many of the solids in the atmosphere are surrounded by a film of condensed water. Small water droplets, together with the dust, vegetative material, and salt, form an envelope of haze about the Earth. Over the greater part of the Earth, this haze scatters light and restricts visibility to much less than would be encountered in pure, dry air. The liquid water droplets are also very effective in absorbing radiation in the infrared portion of the spectrum.

Droplets of liquid water often grow in size to the point where their size severely restricts the transmittance of radiation in both the visible and infrared. The result can be seen visually as fog. Even more common is the sudden condensation of water vapor into liquid water aloft, with a cloud resulting. Cloud droplets are much larger than haze droplets, and thus can settle faster. Cloud droplets often grow so large that they fall to the Earth as rain. More frequently, liquid droplets comprising a cloud, freeze into ice crystals or snow, and fall.

TABLE 1. - NORMAL COMPOSITION OF CLEAN, DRY ATMOSPHERIC AIR NEAR SEA LEVEL

[From ref. 1]

Constituent gas and formula	Content, percent by volume	Content variable relative to its normal	Molecular weight (a)
Nitrogen (N_2)	78.084	---	28.0134
Oxygen (O_2)	20.9476	---	31.9988
Argon (Ar)	0.934	---	39.948
Carbon dioxide (CO_2)	0.0314	(b)	44.00995
Neon (Ne)	0.001818	---	20.183
Helium (He)	0.000524	---	4.0026
Krypton (Kr)	0.000114	---	83.80
Xenon (Xe)	0.0000087	---	131.30
Hydrogen (H_2)	0.00005	?	2.01594
Methane (CH_4)	0.0002	(b)	16.04303
Nitrous oxide (N_2O)	0.00005	---	44.0128
Ozone (O_3)	Summer: 0 to 0.000007	(b)	47.9982
	Winter: 0 to 0.000002	(b)	47.9982
Sulfur dioxide (SO_2)	0 to 0.0001	(b)	64.0628
Nitrogen dioxide (NO_2)	0 to 0.000002	(b)	46.0055
Ammonia (NH_2)	0 to trace	(b)	17.03061
Carbon monoxide (CO)	0 to trace	(b)	28.01055
Iodine (I_2)	0 to 0.000001	(b)	253.8088

[a] On basis of carbon-12 isotope scale for which $C^{12} = 12$.

[b] The content of the gases marked with a dagger may undergo significant variations from time to time or from place to place relative to the normal indicated for those gases.

Thus, the atmosphere at any given time holds vast quantities of non-gaseous material. Since these non-gaseous materials, especially clouds, are generally opaque to infrared radiation and strongly reflect solar radiation, they are very important to radiative considerations. Further, because clouds may extend to 22 kilometers or more, they penetrate to levels where non-window atmospheric radiation, even in the very opaque regions, originates, and cause satellite channels in these regions to become contaminated by cloud-top radiation in addition to the radiation from the gases (ref. 2).

<u>The shape of the atmosphere.</u> -- As a gas confined to the Earth by gravity, the height of a given density level of the atmosphere is partly governed by the acceleration of gravity at that point. Farther out, and beyond the region of consideration here, the atmosphere undergoes shaping by the solar wind.

The lower boundary of the atmosphere is shaped by the irregular topography of the Earth. Mountains, hills, and valleys give the lower boundary an irregular shape. Where water rather than land exists, the atmosphere-water boundary is shaped by the waves, the tides, and the uneven height of the sea caused by the mean motion of the air itself over long distances.

Despite the irregular shape of the atmosphere, and lack of precise knowledge of the high atmosphere, the total mass of the atmosphere is known to within an uncertainty of less than one percent (ref. 3).

<u>Atmospheric altitude regions.</u> -- The atmosphere of the Earth has been divided into various "spheres of altitude" by various workers, the division usually being dictated by the interest of the particular scientific discipline.

In reality, the layers of atmosphere cannot be thought of as having sharp boundaries. Indeed, even the air-ocean interface is not a sharp boundary; many energy exchanges between the air and ocean exist.

In meteorology, the atmosphere is usually divided into the troposphere, stratosphere, mesosphere, and thermosphere. The tropopause, stratopause, and mesopause form the upper boundaries of the first three of these. The altitudes of these boundaries are not constant in time and space. For example, the tropopause above the tropics is usually quite high, approximately 18 kilometers, is marked by a sharp inflection point in the temperature curve, and undergoes little seasonal variation. The tropopause in the middle latitudes and the polar regions is considerably lower, and undergoes strong seasonal altitude variations, which vary from about 8 to 14 kilometers. The winter tropopause above the polar regions almost disappears completely, being marked by a very weak inflection point in the temperature curve. Above the inflection point, the temperature curve, unlike that of the tropics and mid-latitude, continues to decrease to an altitude of about 30 kilometers. This is much higher than the tropical tropopause, so that the coldest temperatures in the mid-stratosphere occur over the winter pole.

The stratopause, which occurs at an altitude of about 50 kilometers, is a region of high temperature, with temperatures similar to those experienced at the Earth's surface. This is a region in which ultraviolet is strongly absorbed by ozone, which is so absorbent in the ultraviolet, even in small amounts, that it virtually acts as an opaque surface. As a result of the dependence of ozone's ultraviolet absorption at this altitude, the warmest stratopause is found in the high latitude summers where the sun impinges on the ozone layer continuously for long periods. Over the winter pole, the stratopause is much colder, and although it is weak, it is still at a temperature maximum, probably due largely to advection of air at that level from sunlit areas.

The atmosphere may be divided into three regions depending on the techniques used to measure it. The lower atmosphere, to about 30 kilometers is most economically measured by balloons; the middle atmosphere from 30 to 200 kilometers by rocket; and the high atmosphere, above 200 kilometers, by satellite.

MEASUREMENTS OF THE ATMOSPHERE

The Lower Atmosphere

Scientific measurement of the lower atmosphere began in Italy several centuries ago with the invention of the thermometer by Galileo and the invention of the barometer by Toricelli. It was known at an early date that pressure and temperature decreased in general as one ascended a mountain.

Early quasi-vertical measurements of the lower portion of the atmosphere were made by climbing mountains, and in the 19th century, manned balloons were used to make measurements. Around the turn of the 20th century, kites were introduced to make observations on a more regular basis, in addition to unmanned balloons, and later airplanes.

Several decades ago, regular measurements of the troposphere began to appear, with the introduction of the balloon-borne vertically-ascending radiosonde. More recently, the transosonde, or super-pressure constant-density balloon, (which moves horizontally along constant density surfaces) has made its appearance, especially since the development of a system which is not dangerous to aircraft. Further, the vertically ascending radiosonde system has been improved constantly over the past few years, so that heights of about 30 kilometers for an ascent are no longer considered highly unusual.

The Middle Atmosphere

That portion of the atmosphere between 30 and 300 kilometers is perhaps the most poorly documented portion at the present time although many studies have been made in the past few years. The poor documentation is principally due to the face that this portion is too high for most balloons and too low for orbiting satellites. Recent advances in rocketry and in rocket-sensing devices and techniques have contributed much, however, to the present state of knowledge.

In situ investigation of this middle region of the atmosphere began with German-developed rockets. Initial investigation with these rockets began at White Sands Proving Ground on October 10, 1946 (ref. 4). Six data-gathering flights subsequent to that famous flight were made in the ensuing four years.

The 1946 flight produced the first pressure, density, and temperature data in these regions, the rocket being equipped with pressure and density gages. The height of the rocket was tracked optically and by radar. These data, along with several other flights ocurring up to 1952, were analyzed and described by Havens, Koll, and LaGow (ref. 4).

During the 1950's, flights were made with improved rockets, such as the Aerobee at White Sands, and that decade saw the introduction of extensive flights at Guam and Ft. Churchill, Manitoba, to collect data at tropical and sub-polar locations, respectively (ref. 5). New techniques for sounding were also developed and used in this decade, such as rocket grenades, falling spheres, and chaff released and observed on radar.

Rocketry improved in 1958, at which time the solid-fuel Nike-Cajun replaced the liquid-propoelled Aerobee Rocket (ref. 6). Steady improvements in data collection were made in the early 1960's, and this decade has already seen the introduction of the Meteorological Rocket Network (MRN) (ref. 7), consisting of a working agreement and scheduling between various efforts at White Sands, New Mexico; Eglin AFB, Florida; Cape Kennedy, Florida; Wallops Island, Virginia; Tonopah, Nevada; Kindley, Bermuda; Point Mugu, California; Ft. Greely, Alaska; and Ft. Churchill, Manitoba.

Sensing techniques have also improved, notably with the development and introduction of the miniature bead thermistor (ref. 8) aboard a parachute ejected by rocket to measure temperature directly in these middle regions of the atmosphere.

This thermistor has resulted in improved detail of temperature measurements over much of this region. This latter system also employs radar tracking of the parachute to get wind velocities.

The High Atmosphere

The high atmosphere is that part (from about 200 kilometers upward) which lacks sufficient density to preclude the orbital decay of an artificial satellite for at least a small number of orbits. The in situ study of this portion of the atmosphere was initiated with the celebrated flight of Sputnik I by the Soviet Union in 1957. In the near-decade since that time, accelerating knowledge of this region of the atmosphere has continued on up to the present day.

Although this portion of the atmosphere is highly deserving of study, not much need be said concerning it here since it is not of grave importance to what is to follow, the density is too low to contribute significantly to the radiance profile.

MODELING THE ATMOSPHERE

Average Atmosphere

If extensive observations of the basic parameters of the entire atmosphere of the Earth were made at equal intervals of space and time, these observations averaged together could perhaps determine an average atmosphere for the Earth. Some account would, of course, have to be made for the fact that while most observations would be made at sea level, many would have to be made from high plateaus and mountains.

If this were done, it would be found that such an atmosphere would probably never exist in nature, and that the average atmosphere might not even be mathematically consistent, if independent observations of the defining parameters were made.

In most areas, comparison of the individual observations made in a particular spot would not be similar from the winter season to the summer. Additionally, an observation of the atmospheric vertical profile made in the tropics would probably never match one taken in the polar regions.

Observational data at present preclude the accomplishment of such a feat, but from the standpoint of constructing a "true average atmosphere" the execution of such a construction would result in no great useful purpose beyond academic interest. Further, we already have at our disposal an approach to documenting the atmosphere that is satisfactory for most applications, namely, the concept of a model atmosphere.

The Model Atmosphere Concept

A model atmosphere is a representation of the relation between pressure, temperature, and density which is mathematically consistent with the equation of state and the hydrostatic equation [Equations (1) and (2)], and which approximates values of these three parameters typically found in a particular geographical region or climatic zone of the Earth, perhaps in a particular season.

Attempts at the construction of a model atmosphere began about a century ago. With the advent of World War I, more accurate information was needed by aircraft designers and artillery personnel on the pressure and temperature to be expected (ref. 9). Observations of these parameters were the most plentiful in Europe, and workers on both sides of the battle lines generated model atmospheres. These atmospheres were constructed analytically to provide consistency between pressure and density.

In 1919, Toussaint proposed a model atmosphere which had certain desirable qualities which still govern model atmosphere construction today. Toussaint's model did not purport to be an average atmosphere, since it excluded the variable gas, water vapor, from the model. He did use, however, accepted international units of measurement. Outstandingly, he used a segmented straight-line function for temperature change with height, rather than a smooth curve to represent his model. A straight-line segmented function has the advantage of simplicity and ease-of-handling of points intermediate between chosen values.

Toussaint, working in 1919, had the benefit of a fair amount of data which the workers of a decade earlier did not have. Thus, he was able to generate a model which was valid. Toussaint took temperatures as the basic parameter for constructing his atmosphere. He chose a temperature of 15 degrees Celsius for his model value of temperature at sea-level, and a constant temperature gradient of -0.0065°C/meter from sea-level to 11 000 meters. The tropopause was defined to be at 11 000 meters with a temperature of -56.5°C. This temperature value is interdependent with his values of surface temperature and temperature gradient. From 11 to 20 kilometers, the temperature was kept constant at -56.5°C, since this is the region partly comprising the stratosphere.

Toussaint's work was so outstanding that his basic approach and formulations have since been used as a basis for all acceptable model atmospheres. A glance at pages 39 and 45 of the latest U.S. Standard Atmosphere (ref. 1) reveals a standard temperature of 15.0 degrees Celsius at sea level and a temperature of -56.5 degrees Celsius at 11 000 meters (which is still the model height of the tropopause), which are Toussaint's exact values. His practice of using temperature as the basic defining parameters has also been followed by subsequent workers.

Toussaint's model was based on data gathered in the lower atmosphere of the middle latitudes, largely in the warring nations of World War I. Thus, the values appearing in his model are applicable to mid-latitude nations. Since that time, planning and design demands have required atmospheric models for various seasons of the year, major climatic regions, and for higher altitude. Consequently, models which have made their appearance in recent years bear such names as "arctic winter" and "tropical". Although these models, naturally, do not use Toussaint's mid-latitude temperature values and extend to much higher altitudes, they do preserve many of Toussaint's proposals, such as straight-line segmentation of temperature.

Standard Atmospheres

Scientists in several nations recognized the advantage of having one model atmosphere as a common reference. As a result Toussaint's basic model was adopted in Europe, and became the general accepted standard. However, in the United States in 1922, Gregg formulated a U. S. Standard Atmosphere. Gregg's standard was analytic to only about 10 kilometers; between 10 and 20 kilometers he merely presented observed data.

In 1924, the model based on Toussaint's temperature-altitude function was adopted as the international standard by the International Committee on Air Navigation (ICAN). The standard was also accepted throughout Europe.

However, the very next year in the United States, Diehl modified, extended, and amplified Gregg's work, redrew the tropopause at 65 000 feet (using English units), and used a temperature of -55 degrees Celsius as his tropopause value. This became the next U.S. Standard Atmosphere.

Other revisions to the U.S. standard were made by Brombacher in 1926 and 1935. It was not until 1952 that the U. S. Standard Atmosphere and the European atmosphere agreed. The United States agreed to accept the ICAN values of tropopause altitude and tropopause temperature, while Europe agreed to accept the United States sea-level value of gravity.

After World War II, other workers were concerned with the upward extension of the standard atmosphere, because of the interest generated by the rocket firings at White Sands. Models appeared in 1947 and 1948 by Warfield and Grimminger, respectively; in 1952 and 1953, meetings were held for interested scientists to examine and discuss rocket data. Various proposals and models were generated, and eventually an extension proposed by Minzner (who gives an interesting account of the meetings in his paper (ref. 10), as well as fine details on the other material in this section) was adopted. As a result of Minzner's proposals, a model atmosphere to 130 kilometers was adopted.

As more and better rocket data became available, the ARDC model and extension to the U.S. Standard Atmosphere was generated in 1956. This atmosphere was tabulated to just over 542 kilometers.

With the increase in knowledge of atmospheres by the information generated by high-rising radiosondes, rockets and satellites between 1956 and 1962, a new model atmosphere to greater heights and to greater accuracy became possible; in 1962, the Committee on Extension to the Standard Atmosphere (COESA) adopted a new U.S. Standard Atmosphere. This model atmosphere, which gives tabulations to 700 kilometers, divides the atmosphere into four altitude regions of geopotential altitude, based on the increasing uncertainty of information. The region from -5 to 20 geopotential kilometers is designated proposed; from 30 to 90 geopotential kilometers is designated tentative; and from 90 to 700 geopotential kilometers is designated as speculative. Note that only the lowest 20 geopotential kilometers are regarded as standard.

The 1962 Atmosphere uses a sequence of connected linear segments for temperature, following Toussaint's method, but above 100 kilometers is uses a smoothed curve for molecular scale temperature. The tables are given in both geopotential units and geometric units to 90 kilometers (km), but only in geometric altitude units above 90 km. Entries appear for both metric and English units.

In addition, the 1962 Atmosphere carefully lists all units which are used in the calculations (see Table 2) and gives defining equations by which the meteorological parameters are derived. To enable the user to better visualize the parameters involved, graphs appear relating the value of each parameter to altitude. Some of the more important of these are reproduced in Figures 1 to 4.

TABLE 2. - ADOPTED PRIMARY CONSTANTS, ATMOSPHERIC
[From ref. 1]

Name	Symbol	Metric units (mks)	English Units (ft-lb-sec)
Sea level pressure	P_o	1.013250×10^5 newtons m^{-2}	2116.22 lb ft^{-2}
Sea level density	ρ_o	1.2250 kg m^{-3}	0.076474 lb ft^{-3}
Sea level temperature	t_o	15° C	59.0°F
Sea level gravity	g_o	9.80665 m sec^{-2}	32.1741 ft sec^{-2}
Sutherland's constant	S	110.4°K	198.72°R
Ice point temperature	T_4	273.15°K	491.67°R
Constant	β	1.458×10^{-5} kg $sec^{-1} m^{-1} (°K)^{-1/2}$	7.3025×10^{-7} lb ft^{-1} sec^{-1} $(°R)^{-1/2}$
Ratio of specific heats	γ	1.40 (dimensionless)	1.40 (dimensionless)
Mean collision diam., Air	σ	3.65×10^{-10}m	1.1975×10^{-9} ft
Avogadro's number	N	6.02257×10^{26} $(kg\text{-}mol)^{-1}$	2.73179×10^{26} $(lb\text{-}mol)^{-1}$
Universal gas constant	R*	8.31432 joules $(°K)^{-1}$ mol^{-1}	1545.31 ft lb $(lb\text{-}mol)^{-1}$ $(°R)^{-1}$

Since the issuance of this most recent atmosphere for mid-latitudes, atmospheres have been generated to 90 kilometers for arctic winter, arctic summer, and mean tropical atmospheres. These have been given the name U.S. Air Force Interim Atmospheres by Kantor and Cole at the Air Force Cambridge Research Laboratories (AFCRL).

More recently special atmospheres have been generated to represent, by month, conditions to 80 kilometers at three latitudes, 30°N, 45°N, and 60°N. Kantor and Cole, working with latitude circles, rather than regions, equate these models to approximately mean conditions at the above latitudes, although

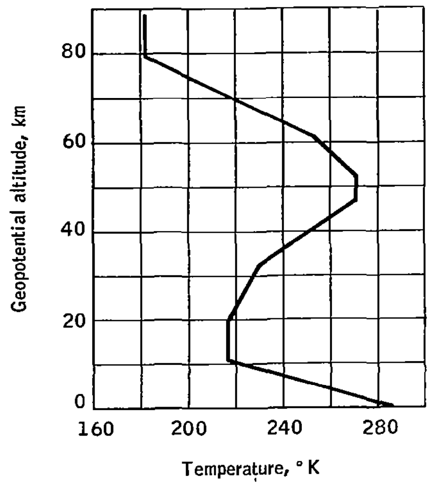

Figure 1. Temperature T as a Function of Geopotential Altitude H

[From ref. 1]

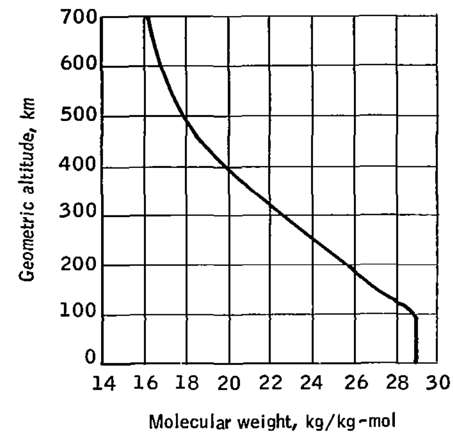

Figure 2. Molecular Weight M as a Function of Geometric Altitude Z

[From ref. 1]

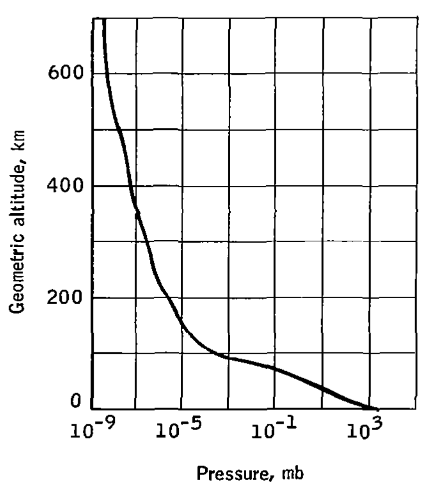

Figure 3. Pressure P as a Function of Geometric Altitude Z

[From ref. 1]

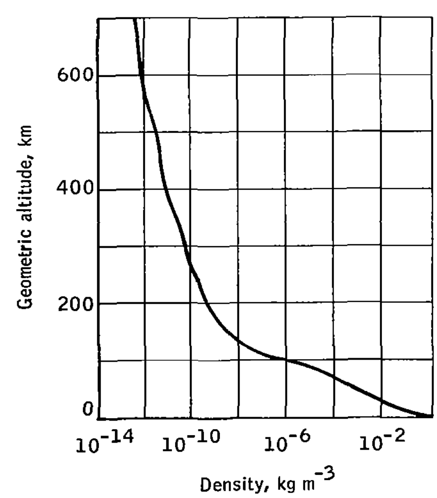

Figure 4. Density P as a Function of Geometric Altitude Z

[From ref. 1]

the data above balloon heights were taken only over North America and parameters were defined using temperature in straight-line segments. Thus, they are more a model than an average, although they perhaps more accurately represent average conditions than do other models. Their values, given as tables in 5000 geopotential meter intervals, appear in Tables 3, 4, and 5 for latitudes 30°N, 45°N, and 60°N, respectively. Their correspondence to subtropical, mid-latitude, and sub-arctic climatic regimes might be noted. Because of their wide latitudinal range and breakdown, their monthly values are perhaps better suited than any other known values to certain radiative transfer problems where detail is important. Kantor and Cole (personal communication, 1966) are currently working on the extension of these latitude circle model atmospheres to 700 kilometers.

Sample Atmosphere

An average or standard atmosphere provides the general atmospheric characteristics, but only describes spatial and temporal variations in the most gross sense. For the Horizon Definition Study, the spatial and temporal variations in the 15 micron radiance of the Earth were of principal interest. To determine the variations, it was necessary to compute approximately 1000 infrared horizon randiance profiles and subject them to a statistical analysis. As inputs for the computations, it was necessary to generate a sample of the Earth's atmosphere. Using a carefully selected sample, approximately 1000 temperature profiles extending from the surface to 90 km were generated. A complete description of the data inputs, as well as the procedures used to generate the profiles, are described in Reference 11.

To obtain a reasonably complete picture of temperature variability, three different types of data presentation were used: (1) variations in space at a fixed time over an area roughly 1/3 of the Northern Hemisphere (synoptic cases); (2) variations in space at a fixed time along a cross section of approximately 5600 km; and (3) variations in time at a fixed point. Temperature profiles for the various methods of data presentation were obtained such that seasonal and latitudinal variability could be examined. In addition, seasonal climatological data was procured so that the individual profiles can be compared with the climatological normals.

Sources of data. -- The real time data were obtained from two basic sources. In the region from 0-30 km, the radiosonde network provided temperatures at 12-hour intervals. The radiosonde network is quite dense over North America and provides temperature measurements generally accurate to ±1°C. All radiosonde information was gathered in the form of microfilmed charts from the National Weather Records Center at Asheville, North Carolina. Temperatures in the 30-60 km layer were obtained from a series of publications entitled "Data Report of the Meteorological Rocket Network Firings" which is published monthly. The rocket data are reduced and prepared by the U.S. Army Electronics Research and Development Activity at White Sands Missile Range in New Mexico. Above 60 km rocket measurements are rarely made. As a result, an extrapolation technique using temperatures

TABLE 3. - MEAN MONTHLY ATMOSPHERIC PROPERTIES, 30° N
[From ref. 12]

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	287.15	286.55	289.15	292.15	295.15	298.65	301.15	298.65	296.65	293.65	289.15	286.15
5000	261.65	264.15	262.65	267.15	271.15	272.65	271.65	272.15	272.15	268.65	266.15	261.25
10000	229.15	231.65	230.15	232.15	233.65	235.15	238.15	239.95	234.65	233.65	231.15	229.75
15000	208.35	209.95	210.55	210.95	208.15	203.65	203.15	206.95	207.65	207.65	208.75	209.05
20000	208.15	208.15	210.15	211.15	211.55	212.05	211.95	210.65	211.75	211.15	209.15	209.65
25000	219.15	218.15	220.15	221.65	223.05	222.55	222.15	220.65	222.25	221.25	219.65	219.85
30000	229.15	228.15	231.05	231.65	234.55	233.05	232.15	230.65	230.75	229.75	227.15	226.85
35000	240.35	239.65	242.55	242.85	246.05	245.15	243.35	242.15	241.65	240.65	237.95	237.45
40000	252.35	252.15	254.05	254.85	257.55	257.65	255.35	254.65	254.15	253.15	250.95	250.45
45000	264.35	264.65	265.55	266.85	269.05	270.15	267.35	267.15	266.65	265.65	263.95	263.45
50000	269.15	269.65	270.15	271.65	273.65	272.65	272.15	272.15	271.65	270.65	269.15	268.65
55000	261.15	263.65	262.15	261.55	263.65	262.65	264.15	266.15	263.65	264.65	263.15	262.65
60000	250.05	254.35	250.95	248.45	250.35	249.35	252.35	256.55	252.35	255.25	253.85	253.45
65000	234.55	237.85	234.95	232.45	233.85	232.85	233.35	238.55	235.85	238.25	237.35	237.45
70000	219.05	221.35	218.95	216.45	217.35	216.35	214.35	220.55	219.35	212.25	220.85	221.45
75000	203.55	204.85	202.95	200.45	200.85	199.85	195.35	202.55	202.85	204.25	294.35	205.45
79000	191.15	191.65	190.15	187.65	187.65	186.65	180.15	188.15	189.65	190.65	191.15	192.65
						Pressure (mb)						
0000	1.0210	1.0190	1.0180	1.0170	1.0155	1.0140	1.0135	1.0135	1.0150	1.0170	1.0190	1.0200+3*
5000	5.5020	5.4909	5.4860	5.5191	5.5530	5.5692	5.5700	5.5612	5.5556	5.5372	5.5208	5.4866+2
10000	2.7402	2.7540	2.7400	2.7812	2.8188	2.8385	2.8515	2.8540	2.8278	2.8017	2.7743	2.7334
15000	1.2437	1.2601	1.2499	1.2732	1.2888	1.2958	1.3127	1.3269	1.2953	1.2826	1.2638	1.2144
20000	5.4096	5.5011	5.4942	5.6030	5.6479	5.6768	5.7429	5.7963	5.6629	5.6032	5.5031	5.4289+1
25000	2.4342	2.4680	2.4834	2.5460	2.5729	2.5861	2.6146	2.6247	2.5826	2.5469	2.4887	2.4589
30000	1.1359	1.1478	1.1638	1.1981	1.2193	1.2216	1.2325	1.2310	1.2148	1.1940	1.1584	1.1444
35000	5.4820	5.5235	5.5654	5.8269	5.9888	5.9757	6.0030	5.9704	5.8846	5.7660	5.5450	5.4696+0
40000	2.7400	2.7572	2.8426	2.9327	3.0386	3.0286	3.0255	3.0012	2.9539	2.8863	2.7565	2.7151
45000	1.4143	1.4234	1.4727	1.5234	1.5881	1.5852	1.5736	1.5591	1.5327	1.4938	1.4195	1.3964
50000	7.4804	7.5365	7.8087	8.1051	8.4892	8.4673	8.3819	8.3041	8.1536	7.9284	7.5066	7.3756−1
55000	3.9351	3.9771	4.1177	4.2810	4.5052	4.4830	4.4410	4.4083	4.3150	4.1939	3.9566	3.8829
60000	2.0192	2.0602	2.1183	2.1925	2.3193	2.3019	2.2961	2.2977	2.2284	2.1779	2.0470	2.0063
65000	0.9975	1.0289	1.0484	1.0772	1.1450	1.1331	1.1359	1.1521	1.1065	1.0896	1.0208	1.0001
70000	4.6956	4.8878	4.9376	5.0310	5.3683	5.2945	5.2936	5.4721	5.2224	5.1789	4.8417	4.7491−2
75000	2.0914	2.1919	2.1962	2.2161	2.3707	2.3289	2.2980	2.4393	2.3242	2.3193	2.1671	2.1326
79000	1.0462	1.0999	1.0955	1.0956	1.1728	1.1480	1.1094	1.2115	1.1581	1.1606	1.0856	1.0731
						Density (kg/m^3)						
0000	1.2387	1.2384	1.2265	1.2127	1.1986	1.1828	1.1724	1.1822	1.1920	1.2065	1.2277	1.2418+0*
5000	7.3255	7.2416	7.2764	7.1970	7.1344	7.1159	7.1431	7.1186	7.1116	7.1802	7.2263	7.3162−1
10000	4.1657	4.1416	4.1474	4.1734	4.2028	4.2051	4.1712	4.1435	4.1982	4.1773	4.1812	4.1447
15000	2.0796	2.0908	2.0680	2.1026	2.1570	2.2166	2.2510	2.2337	2.1731	2.1517	2.1091	2.0738
20000	9.0537	9.2069	9.1078	9.2441	9.3007	9.3262	9.4393	9.5858	9.3165	9.2444	9.1662	9.0209−2
25000	3.8694	3.9412	3.9297	4.0016	4.0184	4.0481	4.1002	4.1440	4.0481	4.0101	3.9472	3.8963
30000	1.7269	1.7525	1.7547	1.8018	1.8110	1.8261	1.8494	1.8593	1.8339	1.8104	1.7766	1.7574
35000	7.9457	8.0292	8.1242	8.3587	8.4792	8.4917	8.5937	8.5893	8.4833	8.3469	8.1181	8.0246−3
40000	3.7825	3.8093	3.8980	4.0089	4.1101	4.0950	4.1277	4.1057	4.0490	3.9720	3.8266	3.7766
45000	1.8638	1.8736	1.9320	1.9888	2.0563	2.0442	2.0505	2.0332	2.0024	1.9590	1.8735	1.8465
50000	0.9682	0.9737	1.0070	1.0394	1.0807	1.0819	1.0729	1.0630	1.0456	1.0205	0.9716	0.9564
55000	5.2494	5.2551	5.4719	5.6999	5.9528	5.9460	5.8570	5.7701	5.7016	5.5206	5.2379	5.1501−4
60000	2.8131	2.8217	2.9406	3.0743	3.2274	3.2160	3.1697	3.1201	3.0762	2.9725	2.8091	2.7577
65000	1.4815	1.5069	1.5545	1.6144	1.7058	1.6952	1.6958	1.6825	1.6344	1.5932	1.4983	1.4673
70000	7.4676	7.6926	7.8562	8.0971	8.6043	8.5252	8.6033	8.6434	8.2942	8.1544	7.6372	7.4709−5
75000	3.5794	3.7276	3.7699	3.8514	4.1119	4.0596	4.0980	4.1954	3.9915	3.9558	3.6944	3.6160
79000	1.9067	1.9993	2.0071	2.0339	2.1773	2.1426	2.1453	2.2432	2.1273	2.1207	1.9784	1.9405

* Power of ten by which preceding numbers should be multiplied.

TABLE 4. - MEAN MONTHLY ATMOSPHERIC PROPERTIES, 45° N
[From ref. 12]

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	272.15	273.15	274.15	279.15	284.65	288.15	294.15	292.15	288.15	284.15	278.15	273.15
5000	249.65	249.65	253.15	257.15	260.15	263.40	267.15	265.40	262.40	257.15	254.15	251.15
10000	219.65	217.15	223.15	224.65	225.15	231.90	235.15	231.90	230.90	227.15	224.15	218.65
15000	217.15	217.15	217.15	218.15	218.15	216.15	215.65	215.15	215.15	215.15	215.35	216.15
20000	215.15	217.15	217.15	218.15	218.15	219.45	219.25	218.75	217.65	215.15	214.65	216.15
25000	215.15	219.65	220.15	221.65	223.15	224.95	225.25	224.75	222.65	220.15	218.65	216.15
30000	219.90	224.65	225.15	228.65	231.65	233.15	233.65	233.15	227.65	225.15	222.65	216.15
35000	229.90	231.65	233.40	239.15	244.90	245.40	245.40	244.40	239.15	234.15	229.65	227.90
40000	240.65	242.15	246.65	252.40	258.40	259.15	258.40	257.40	251.90	246.90	241.90	241.40
45000	255.60	255.90	260.65	264.65	268.90	269.65	268.15	268.40	268.65	258.90	255.15	257.15
50000	264.40	263.40	266.65	269.40	272.40	273.40	271.65	271.40	269.40	265.40	262.65	265.40
55000	259.90	258.15	258.65	262.15	265.90	267.65	268.40	265.15	262.40	262.40	259.15	264.15
60000	247.65	247.90	244.15	251.15	253.15	254.65	256.65	253.15	248.40	251.90	249.65	255.65
65000	238.65	237.40	233.15	238.15	235.90	238.65	235.40	233.65	232.15	238.40	239.15	241.90
70000	232.15	227.40	225.40	222.90	216.90	216.40	212.15	213.15	213.65	223.65	225.15	226.65
75000	218.65	218.15	216.90	207.15	198.40	191.40	190.15	194.65	196.15	207.90	211.15	212.65
79000	206.65	210.95	209.30	193.55	182.80	173.40	171.85	177.85	183.35	195.50	201.55	203.85
						Pressure (mb)						
0000	1.0180	1.0165	1.0160	1.0150	1.0145	1.0130	1.0135	1.0150	1.0165	1.0175	1.0180	1.0180+3*
5000	5.3072	5.3097	5.3368	5.3928	5.4428	5.4709	5.5224	5.5176	5.4805	5.4178	5.3714	5.3316+2
10000	2.5602	2.5510	2.6024	2.6509	2.6888	2.7422	2.7963	2.7730	2.7393	2.6734	2.6271	2.5736
15000	1.1711	1.1617	1.1876	1.2143	1.2319	1.2614	1.2924	1.2721	1.2556	1.2189	1.1983	1.1730
20000	5.3098	5.2900	5.4080	5.5497	5.6300	5.7439	5.8760	5.7735	5.6891	5.5103	5.4085	5.3222+1
25000	2.4004	2.4144	2.4707	2.5442	2.5959	2.6627	2.7244	2.6722	2.6185	2.5137	2.4584	2.4148
30000	1.0898	1.1191	1.1471	1.1914	1.2211	1.2608	1.2919	1.2651	1.2262	1.1671	1.1335	1.0956
35000	5.0963	5.2839	5.4308	5.7231	5.9557	6.1632	6.3226	6.1799	5.8972	5.5287	5.3123	5.0765+0
40000	2.4649	2.5660	2.6616	2.8573	3.0225	3.1325	3.2098	3.1268	2.9442	2.7177	2.5693	2.4471
45000	1.2347	1.2905	1.3580	1.4758	1.5830	1.6441	1.6804	1.6351	1.5173	1.3834	1.2931	1.2328
50000	6.4418	6.7176	7.1345	7.8173	8.4457	8.7858	8.9418	8.7112	8.0229	7.2327	6.7035	6.4418−1
55000	3.3637	3.4996	3.7390	4.1224	4.4903	4.6867	4.7590	4.6185	4.2366	3.7965	3.4972	3.3829
60000	1.7211	1.7818	1.8943	2.1173	2.3265	2.4394	2.4905	2.3919	2.1708	1.9574	1.7862	1.7593
65000	0.8475	0.8812	0.9238	1.0554	1.1593	1.2210	1.2470	1.1899	1.0674	0.9750	0.8888	0.8851
70000	4.1199	4.2233	4.3841	5.0260	5.4425	5.7846	5.7972	5.5146	4.9601	4.6582	4.2643	4.2737−2
75000	1.9325	1.9611	2.0266	2.2728	2.3919	2.4938	2.4803	2.3908	2.1506	2.1094	1.9449	1.9579
79000	1.0162	1.0372	1.0672	1.1488	1.1673	1.1782	1.1648	1.1473	1.0463	1.0711	1.0028	1.0157
						Density (kg/m³)						
0000	1.3031	1.2964	1.2910	1.2667	1.2416	1.2247	1.2003	1.2103	1.2289	1.2475	1.2750	1.2983+0*
5000	7.4058	7.4093	7.3442	7.3058	7.2885	7.2357	7.2013	7.2425	7.2760	7.3396	7.3626	7.3954−1
10000	4.0606	4.0925	4.0627	4.1108	4.1604	4.1194	4.1426	4.1657	4.1329	4.1001	4.0830	4.1004
15000	1.8788	1.8636	1.9052	1.9392	1.9672	2.0330	2.0877	2.0598	2.0331	1.9737	1.9385	1.8905
20000	8.5976	8.4866	8.6760	8.8624	8.9907	9.1182	9.3364	9.1945	9.1059	8.9221	8.7778	8.5777−2
25000	3.8866	3.8292	3.9096	3.9988	4.0526	4.1236	4.2135	4.1420	4.0971	3.9777	3.9169	3.8919
30000	1.7265	1.7353	1.7749	1.8151	1.8364	1.8838	1.9262	1.8903	1.8764	1.8058	1.7736	1.7659
35000	7.7224	7.9462	8.1059	8.3368	8.4719	8.7492	8.9755	8.8089	8.5724	8.2256	8.0585	7.7599−3
40000	3.5683	3.6916	3.7593	3.9437	4.0748	4.2109	4.3274	4.2318	4.0718	3.8346	3.7002	3.5314
45000	1.6825	1.7568	1.8150	1.9426	2.0508	2.1241	2.1830	2.1223	2.0048	1.8615	1.7655	1.6700
50000	0.8488	0.8884	0.9321	1.0109	1.0801	1.1195	1.1467	1.1182	1.0375	0.9494	0.8891	0.8456
55000	4.5087	4.7226	5.0360	5.4783	5.8829	6.1002	6.1769	6.0680	5.6246	5.0403	4.7011	4.4615−4
60000	2.4210	2.5039	2.7029	2.9369	3.2016	3.3372	3.3806	3.2916	3.0444	2.7071	2.4925	2.3973
65000	1.2371	1.2931	1.3803	1.5438	1.7120	1.7824	1.8454	1.7741	1.6017	1.4248	1.2947	1.2746
70000	6.1810	6.4699	6.7759	7.8551	8.7414	9.3123	9.5195	9.0130	8.0878	7.2559	6.5981	6.5688−5
75000	3.0790	3.1318	3.2550	3.8222	4.1998	4.5390	4.5441	4.2789	3.8195	3.5346	3.2088	3.2075
79000	1.7130	1.7129	1.7763	2.0676	2.2246	2.3671	2.3626	2.2474	1.9881	1.9086	1.7334	1.7358

* Power of ten by which preceding numbers should be multiplied.

TABLE 5. - MEAN MONTHLY ATMOSPHERIC PROPERTIES, 60° N

[From ref. 12]

Altitude (geop. m.)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
						Temperature (K)						
0000	257.15	256.65	261.65	269.15	276.65	282.65	287.15	284.15	281.15	275.15	266.15	259.15
5000	240.95	244.90	245.65	250.15	253.25	259.65	260.15	262.15	256.15	252.65	248.65	243.90
10000	217.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	220.15	218.65	217.65
15000	217.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	220.15	218.6	217.65
20000	214.15	218.65	219.65	222.15	223.65	224.65	225.15	224.15	221.15	218.35	216.65	214.15
25000	211.15	219.55	215.15	222.15	223.65	228.65	228.15	227.75	222.15	218.65	214.65	210.65
30000	216.15	222.55	217.65	225.65	231.15	233.65	235.65	232.25	227.15	221.15	219.65	212.65
35000	222.65	225.55	225.35	238.15	244.65	246.65	247.65	245.15	236.65	229.65	224.65	219.65
40000	235.15	236.15	240.85	250.65	259.65	261.65	262.65	260.15	249.15	242.15	235.65	233.15
45000	247.65	248.65	256.35	263.15	270.85	273.05	273.85	271.15	261.65	254.65	248.15	246.65
50000	260.15	261.15	265.65	270.65	274.15	276.65	277.15	275.15	271.65	267.15	260.65	260.15
55000	258.35	259.35	260.65	266.65	269.15	272.65	273.15	269.15	268.75	264.95	259.15	258.65
60000	250.65	251.15	248.15	256.65	256.65	260.05	260.45	252.85	253.35	253.65	251.65	251.15
65000	248.15	246.15	240.15	242.15	236.65	237.05	236.95	231.35	234.35	241.15	243.25	243.65
70000	244.75	240.35	234.15	224.65	216.65	214.05	213.45	209.85	215.35	228.65	231.25	236.15
75000	237.75	231.35	224.15	207.15	196.65	191.05	189.95	188.35	196.35	216.15	219.25	228.65
79000	232.15	224.15	216.15	193.15	180.65	172.65	171.15	171.15	181.15	206.15	209.65	222.65
						Pressure (mb)						
0000	1.0135	1.0140	1.0140	1.0130	1.0125	1.0105	1.0100	1.0105	1.0120	1.0110	1.0212	1.0125+3*
5000	5.1582	5.1916	5.2147	5.2668	5.3293	5.3952	5.4076	5.4051	5.3689	5.3034	5.2373	5.1866+2
10000	2.4160	2.4504	2.4793	2.5302	2.5771	2.6614	2.6715	2.6735	2.6211	2.5719	2.4940	2.4399
15000	1.1002	1.1219	1.1392	1.1728	1.2007	1.2442	1.2510	1.2477	1.2107	1.1838	1.1419	1.1131
20000	4.9826	5.1364	5.2341	5.4359	5.5940	5.8166	5.8583	5.8232	5.5922	5.4384	5.2092	5.0456+1
25000	2.2315	2.3528	2.3856	2.5196	2.6063	2.7338	2.7489	2.7309	2.5839	2.4827	2.3592	2.2576
30000	1.0031	1.0864	1.0834	1.1749	1.2296	1.3056	1.3159	1.2994	1.2079	1.1417	1.0743	1.0072
35000	4.5949	5.0684	4.9826	5.6237	5.9849	6.3943	6.4717	6.3355	5.7657	5.3288	4.9793	4.5697+0
40000	2.1782	2.4120	2.3938	2.7952	3.0392	3.2645	3.3127	3.2216	2.8535	2.5828	2.3655	2.1484
45000	1.0733	1.1920	1.2039	1.4375	1.6004	1.7274	1.7570	1.6983	1.4617	1.2983	1.1673	1.0539
50000	5.4764	6.0979	6.2852	7.6063	8.5635	9.2938	9.4652	9.0955	7.7204	6.7449	5.9638	5.3701−1
55000	2.8388	3.1690	3.2961	4.0389	4.5820	5.0033	5.1013	4.8755	4.1139	3.5568	3.0956	2.7839
60000	1.4488	1.6214	1.6840	2.1023	2.3923	2.6410	2.6959	2.5367	2.1399	1.8410	1.5858	1.4243
65000	0.7304	0.8157	0.8343	1.0623	1.1964	1.3277	1.3558	1.2521	1.0617	0.9228	0.7959	0.7140
70000	3.6558	4.0453	4.0647	5.1078	5.6282	6.2216	6.3457	5.7689	4.9647	4.4591	3.8736	3.5032−2
75000	1.8008	1.9605	1.9286	2.3144	2.4610	2.6746	2.7181	2.4442	2.1640	2.0682	1.8143	1.6797
79000	1.0066	1.0759	1.0367	1.1690	1.1921	1.2607	1.2743	1.1421	1.0487	1.0826	0.9592	0.9167
						Density (kg/m³)						
0000	1.3730	1.3764	1.3501	1.3112	1.2750	1.2454	1.2253	1.2389	1.2540	1.2800	1.3246	1.3611+0*
5000	7.4578	7.3850	7.3952	7.3347	7.3310	7.2386	7.2414	7.1827	7.3018	7.3126	7.3377	7.4082−1
10000	3.8759	3.9041	3.9322	3.9677	4.0142	4.1271	4.1335	4.1551	4.1288	4.0697	3.9737	3.9052
15000	1.7650	1.7874	1.8067	1.8391	1.8792	1.9294	1.9357	1.9392	1.9071	1.8732	1.8193	1.7816
20000	8.1054	8.1837	8.3014	8.5244	8.7136	9.0199	9.0644	9.0503	8.8091	8.6767	8.3763	8.2079−2
25000	3.6816	3.7333	3.8627	3.9512	4.0597	4.1652	4.1973	4.1772	4.0520	3.9556	3.8289	3.7335
30000	1,6167	1.7006	1.7340	1.8138	1.8532	1.9467	1.9454	1.9491	1.8526	1.7985	1.7038	1.6501
35000	7.1894	7.8282	7.7025	8.2264	8.5222	9.0313	9.1037	9.0030	8.4876	8.0836	7.7215	7.2477−3
40000	3.2270	3.5582	3.4624	3.8850	4.0777	4.3464	4.3939	4.3140	3.9898	3.7157	3.4970	3.2102
45000	1.5098	1.6700	1.6360	1.9030	2.0585	2.2039	2.2351	2.1820	1.9461	1.7761	1.6387	1.4886
50000	0.7333	0.8134	0.8242	0.9790	1.0882	1.1703	1.1897	1.1516	0.9901	0.8795	0.7971	0.7191
55000	3.8279	4.2567	4.4053	5.2766	5.9306	6.3928	6.5061	6.3105	5.3327	4.6766	4.1613	3.7496−4
60000	2.0137	2.2490	2.3641	2.8536	3.2473	3.5380	3.6060	3.4950	2.9425	2.5284	2.1953	1.9756
65000	1.0254	1.1544	1.2103	1.5282	1.7612	1.9512	1.9933	1.8854	1.5783	1.3332	1.1399	1.0209
70000	0.5204	0.5863	0.6048	0.7921	0.9050	1.0126	1.0357	0.9577	0.8031	0.6794	0.5835	0.5168
75000	2.6387	2.9521	2.9974	3.8922	4.3596	4.8770	4.9850	4.5207	3.8394	3.3333	2.8827	2.5592−5
79000	1.5105	1.6721	1.6708	2.1084	2.2989	2.5439	2.5937	2.3247	2.0168	1.8295	1.5939	1.4342

* Power of ten by which preceding numbers should be multiplied.

in the 30-60 km layer was developed to supply the temperatures at the higher levels needed for this study. This technique is discussed in detail later in this report.

Corrections to meteorological rocket data. -- The measurement of temperatures above the limits of sounding balloons is difficult. The light-weight and delicate temperature sensor must survive the rigors of boosted flight and, once ejected, reach the temperature conditions of the environment as quickly as possible. As expected, consistent errors are present in the recorded temperature information. Also, the magnitude of the error increases with altitude to the point where Meteorological Rocket Network (MRN) data above 60 km is questionable.

Since the measurements are made with different types of rocket sounding systems throughout the MRN, various corrections are required to produce a set of consistent corrected data. Most of the correcting is performed at the various MRN launching sites and other corrections are performed by the U.S. Army Electronics Research and Development Activity of White Sands Missile Range (WSMR), New Mexico. One of the most frequently used systems of temperature measurement is the Deltasonde employed by WSMR, Fort Greely, Alaska, and Point Mugu, California. Wagner (ref. 13) has developed corrections for data acquired by the Deltasonde. The Wagner correction takes into account effects of compressional or frictional heating, lead wire length and heat conduction through the leads to the thermistor, varying time constant, internal heating and dissipation, solar radiation and the effective infrared radiation temperature below the thermistor. Application of this correction system to the MRN temperature data gathered at WSMR and Forth Greely, Alaska was begun in January 1964. Published Point Mugu data were not corrected in 1964. As a result, GCA, with information furnished by Texas Western College (Neary, Personal Communication, 1966), applied the appropriate corrections to the 1964 Point Mugu data. All other corrections to the 1964 MRN published data were assumed to have been performed by the contributors for the temperature measuring devices other than the Deltasonde. In 1965, all data collection and reduction were accomplished by each contributor to the MRN network. All published 1965 Point Mugu data were corrected by the Wagner method. Lists of all the rocket soundings used in the study and the maximum height at which temperature information is available from each rocket firing are detailed in Reference 11.

Analysis techniques. --

Interpolation: The real time temperature soundings in the 0-30 km layer were obtained from conventional meteorological charts at specified constant pressure levels (called mandatory levels) and from tabulated listings of radiosonde flights in time cross section studies where 12-hour data resolution was required. Also, surface charts were used to obtain the temperature and pressure at the base of the atmospheric column. The constant pressure charts employed were at the 850, 700, 500, 300, 200, 100, 50, 30, and 10 mb levels. Height contours and isotherms are analyzed on every chart. Thus, it was possible to interpolate between the analyzed data at any desired location.

Data in the 30-60 km layer is scarce, and charts are not available on a routine basis. As a result, special charts were prepared using the rocket data from the MRN. If only MRN temperatures were plotted on the charts, analysis of the thermal field at any level would be difficult. However, in addition to the temperature measurements, the rocket soundings included wind measurements. With this information, it is possible to compute the thermal wind and improve the temperature analysis considerably.

The thermal wind is the vector difference between the geostrophic wind at two levels (ref. 14). Therefore, observed wind differences will be equal to thermal wind only when the wind field is geostrophic, i.e., when friction and accelerations are unimportant. Between 30 and 60 km the geostrophic limitations are not considered to be of great importance. Thus, the expression for the thermal wind is:

$$\vec{V}_{thermal} \times \vec{k} = \frac{R}{f}\left(\ln \frac{p}{p'}\right)\left(\frac{\partial \vec{T}}{\partial \hat{n}}\right) \tag{4}$$

where

$\vec{V}_{thermal}$ = the thermal wind

$\vec{k}$ = the unit vector along the vertical axis

R = the gas constant for dry air

f = the Coriolis parameter

p, p' = the pressures at the bottom and top of the layer, respectively,

$\frac{\partial \vec{T}}{\partial \hat{n}}$ = the horizontal temperature gradient normal to thermal wind

The thermal wind is parallel to the isotherms with warm air to the right of the thermal wind facing downwind. Also, the strength of the thermal wind is proportional to the magnitude of the temperature gradient. Thus, with the aid of the thermal wind, temperature analysis could be improved significantly. Also, an MRN report would often contain only wind information. This report would still be of great value for, although the temperature measurements would be missing, the strength and direction of the computed thermal winds would give information on the spacing and direction of the isotherms. In this study, the vertical wind shears were computed every 3 km with the temperature centered in each layer.

The interpolation procedure followed for the climatology data was quite similar to the methods for the real time information. Mean temperature data from the surface to 25 mb were interpolated directly from analyzed charts and tables. Between 100 000 feet (30.5 km) and 170 000 feet (51.8 km) mean temperature and standard deviation charts were plotted and analyzed using MRN information prepared by Quiroz (ref. 15). Then, the interpolation was performed in the same fashion as with the real time data. There were no thermal winds to assist in the analysis of the climatological data. Also, there were fewer data points per chart. Thus, the climatological data in this layer must be considered as speculative.

Extrapolation: As noted earlier, temperature measurements above the 60 km level are a rarity. Such measurements are beyond the present capability of the MRN network on a routine basis; an occasional sounding does go higher than the 60 km level but almost never beyond 65 km. A logical solution to the lack of data above 60 km is to extrapolate from data at lower levels to the higher levels with the use of statistical relationships developed using all of the available information at the higher levels.

Since the 30-60 km region is relatively data-rich, it seems logical to use the temperatures in this layer to extrapolate above 60 km. It was noticed that when the 50 km temperature was colder than the 50 km temperature of the 1962 standard atmosphere, the 80 km temperature appeared to be warmer than the 1962 standard atmosphere temperature at that height. Thirty atmospheric soundings were obtained (ref. 16) where both 50 and 80 km temperatures were measured. These soundings were made over North America. A scatter diagram (Figure 5) was prepared showing the difference between the observed 50 km temperature and the corresponding standard atmosphere temperature as the predictor and the 80 km difference as the predictant. Separate linear correlation coefficients and regression lines were computed for summer (May-October) and winter (November-April). The linear correlation coefficients were 0.62 for summer (14 points) and 0.47 for winter (16 points).

Figures 6 and 7 show how the 50 km and estimated 80 km temperatures were used to obtain temperature values from 63 to 90 km for summer and winter, respectively. First, the 1962 standard atmosphere was plotted on both charts. Then, the 50 km and predicted 80 km temperatures were plotted. These two temperatures were connected by a non-linear curve which assumed the general shape of the standard atmosphere. Above 80 km, isothermal conditions were assumed.

With the curves of Figures 6 and 7 and a knowledge of the 50 km temperature, the temperature could be estimated above the level to 90 km. In nearly all cases, real temperature data were available to heights above 50 km. When this situation occurred, the highest point of real data was used to estimate the temperatures to 66 km and the 50 km temperature for the higher levels. The 66 km level was chosen because the constructed curves cross one another generally at about this level for both summer and winter. Thus, estimation of the high level temperature was based on a combination of the 50 km temperature and the highest point of real data.

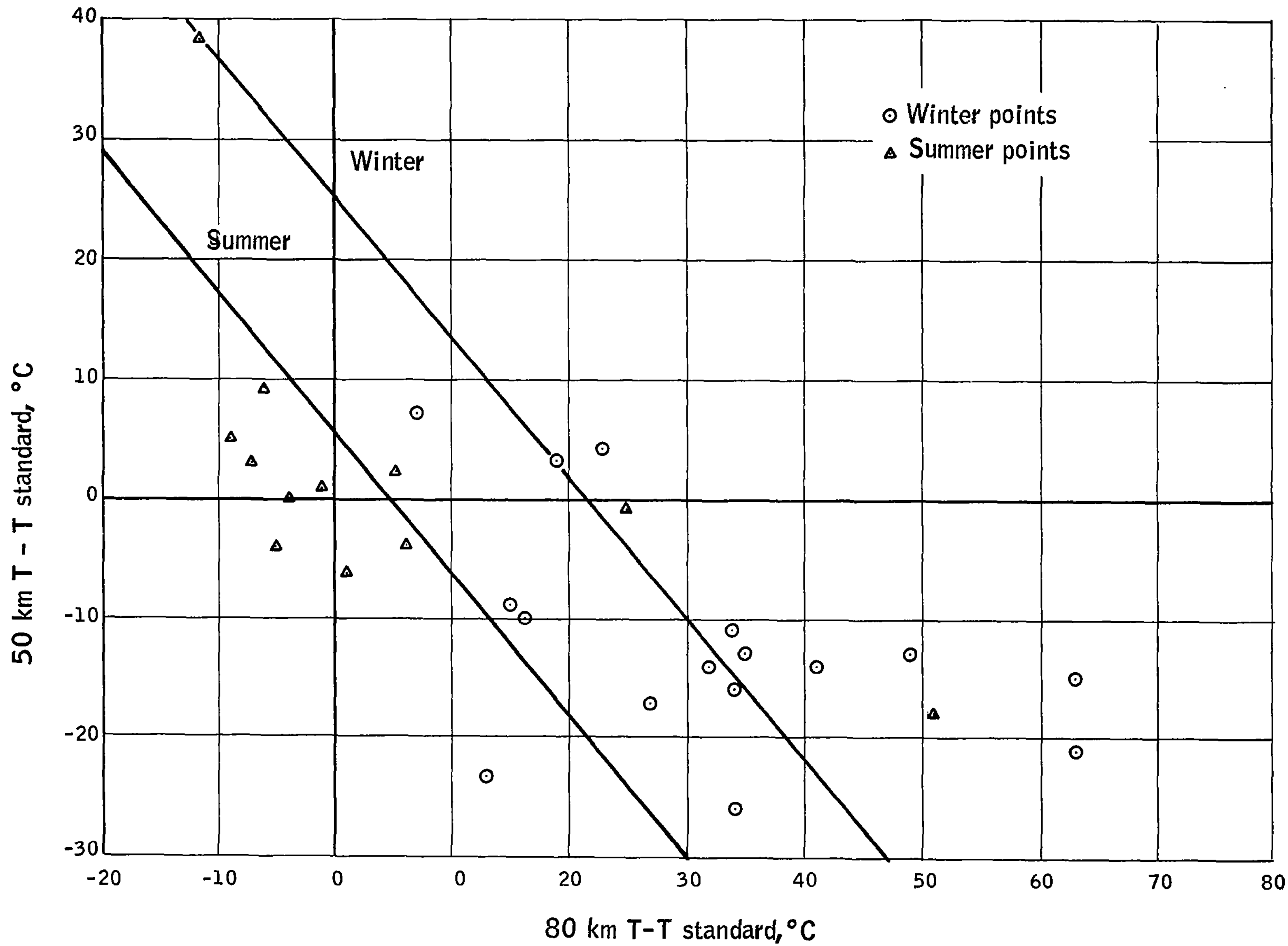

Figure 5. Scatter Diagram, T-T Standard Based on 1962 Standard Atmosphere

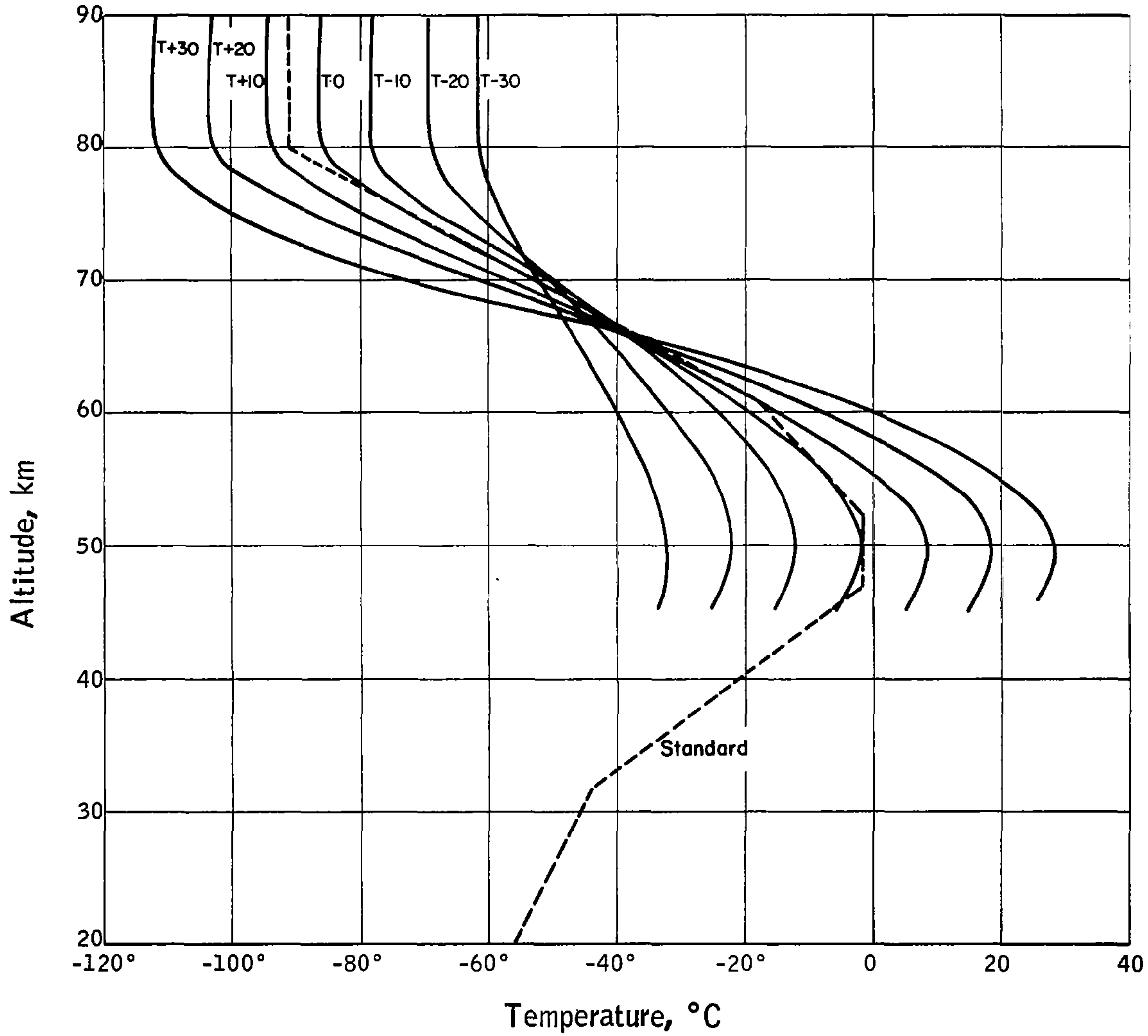

Figure 6. Family of Extrapolated Temperature Profiles Between 50 and 90 KM, Summer

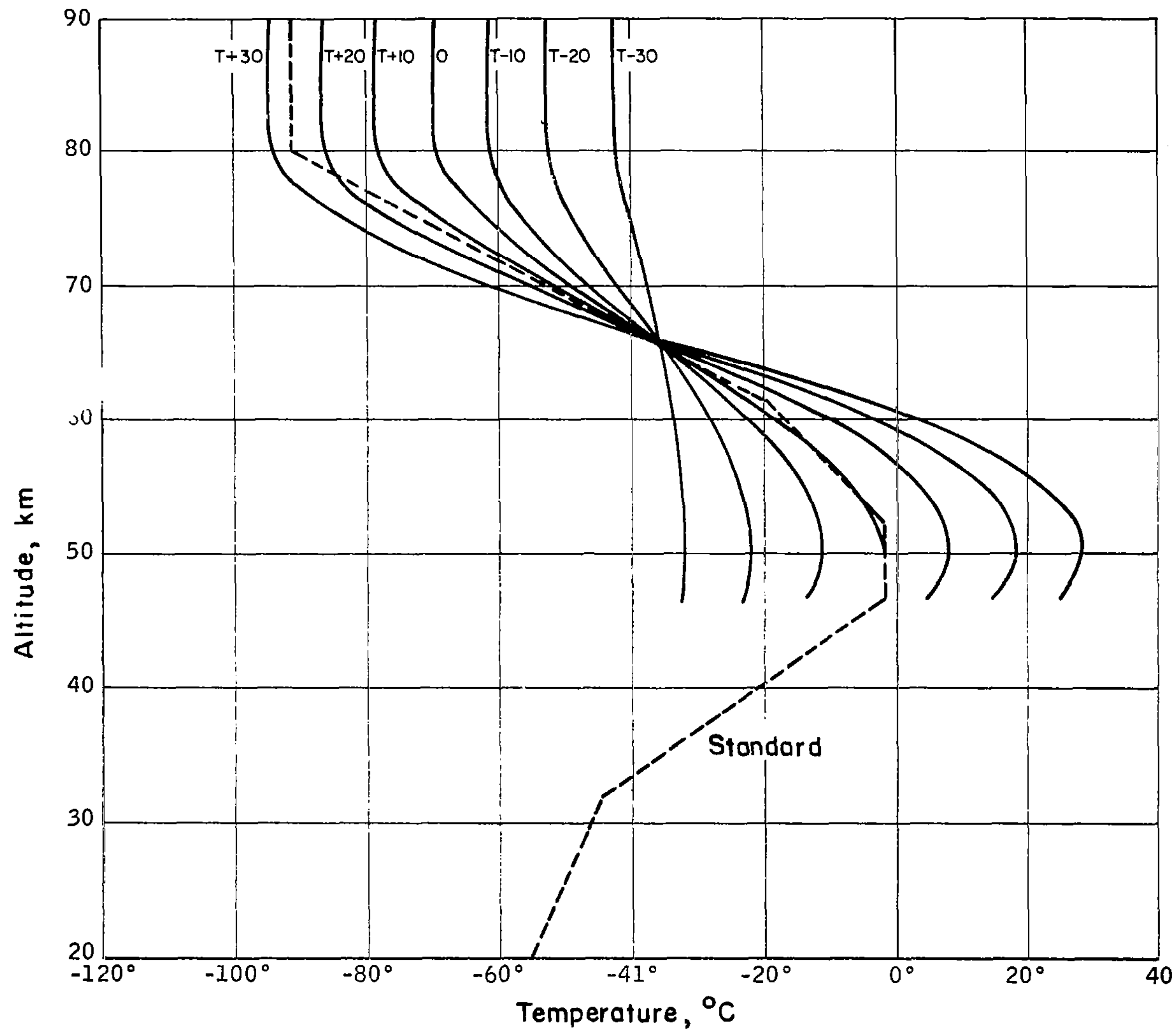

Figure 7. Family of Extrapolated Temperature Profiles Between 50 and 90 KM, Winter

SPECIAL ATMOSPHERIC EFFECTS

ATMOSPHERIC VARIATIONS

Atmospheric models describe a dry atmosphere at a given region and time. In the real atmosphere, air motion is present with accompanying temperature variations in time and space, in addition to H_2O in gaseous, liquid, and solid form.

Water vapor, in all of its forms in the atmosphere, is vital in radiative transfer; tropospheric temperature variations are directly related to the amount of radiative energy leaving the Earth at any given time. Consequently, the departures from a dry, static model or sample of the atmosphere must be considered.

In the radiative transfer problem, only those meteorological variables of concern need be considered. Therefore, the following paragraphs describe atmospheric variations which produce important effects on the radiative transfer problem.

Variation of Water Vapor and Ozone

Variations in water vapor (H_2O in gaseous form) and in ozone (O_3) occur in the atmosphere with respect to altitude, time, and geographic region of the Earth. These variations are of importance to radiative transfer considerations, since water vapor absorbs strongly in the region around 6. 3 microns and in the infrared above 16 microns, and ozone absorbs in the region of 14 microns.

Ozone is found in the altitude region of the atmosphere extending from about 20 to 50 kilometers. A strong absorber of radiation between 2000 and 3000 angstroms (ref. 17), ozone absorbs most of this energy from the sun in its upper layers. So much of this ultraviolet is absorbed in the sparse upper parts of the ozone layer that the ultraviolet which penetrates to the lower layers is too weak to heat the lower, thicker portion of the ozone layer. This results in strong heating of the region known as the stratopause, which marks the region of maximum temperature between the main body of the stratosphere and mesosphere. Ultraviolet radiation from the sun manufactures the ozone; ozone is, therefore, most strongly concentrated in the sunlit regions of the Earth. Ozone concentration reaches its minimum over the poles during the long, polar night, and its variations above the winter pole are due to advection to those regions by stratospheric winds.

Water vapor, which is excluded from model atmosphere calculations, can at times constitute as much as two to three percent of the gaseous content of the atmosphere. Water vapor enters the atmosphere mainly by evaporation from the oceans, seas, lakes, and vegetation. It is transferred to high altitudes by the thermo-dynamic lifting processes in the atmosphere.

The temperature is a determining factor in the amount of water vapor contained in the environmental air. Cold air contains very little water vapor; air near the freezing point of water (0°C) is able to hold less than 0.1 percent of its volume in gaseous form. At temperatures above 30°C, the air can contain from two to three percent of its content as gaseous water vapor.

Because very warm air can only occur at the surface where solar heating is intense, air in excess of 40°C (or even 30°C) is seldom near the saturation point; that is, it does not contain the amount of gaseous water that it could theoretically. Over the oceans, air cannot heat up enough to break the upward limit of about three percent water vapor.

Large amounts of water vapor in the atmosphere are concentrated in the first one or two kilometers. Above these heights, the air is too cold to hold much water vapor; in regions where very much water vapor is present in these low levels, the vapor condenses into the liquid form between one and two kilometers, (or close to these altitudes). Even small amounts of water vapor produce clouds which are quite opaque in both the visible and infrared even at very low temperatures (on the order of -20°C).

It is difficult to measure the small amounts of water vapor existing in the cold temperature of the stratosphere. Radiosonde humidity sensors are too crude to measure even what can be considered comparatively large amounts of water vapor in the tropopause.

Limited measurements of water vapor in the stratosphere have recently been taken with such sensors as the alpha particle frost-point hygrometer (ref. 18). Brown and Pybus (ref. 19) give the results of stratospheric water vapor measurements made from the Naval Air Facility at McMurdo Sound with a Ballistic Research Laboratory frost-point hygrometer. They present a graph of water vapor mixing ratios showing their results and values obtained by other investigations. This graph is reproduced here in Figure 8.

Liquid and Solid H_2O in the Atmosphere

Condensation. -- Since the amount of water vapor that the air can contain is a function of the temperature, it follows that if a volume of air decreases in temperature to the point (the dew point) where it can no longer contain the vapor, the vapor must be ejected from the volume of air. This removal of water vapor from the air is called condensation, and the visible evidence of condensation is a cloud in either the liquid or solid form. This aggregate of liquid and/or solid water is quite opaque to radiation in both the visible and the infrared region. In the infrared region, if a cloud is of great thickness and concentration, it behaves very nearly as a black body.

In actuality, some water vapor often condenses out into the atmosphere even before it drops to the dew point. Most dust and salt particles in an atmosphere that is moist (humidity over 70 percent) have considerable amounts of condensed water on them. This accounts for the rather thick haze that can be seen over humid areas on photographs from the Mercury and Gemini missions. In contrast, very dry regions, such as the deserts and high plateau regions, notably Tibet, exhibit very clear atmospheres.

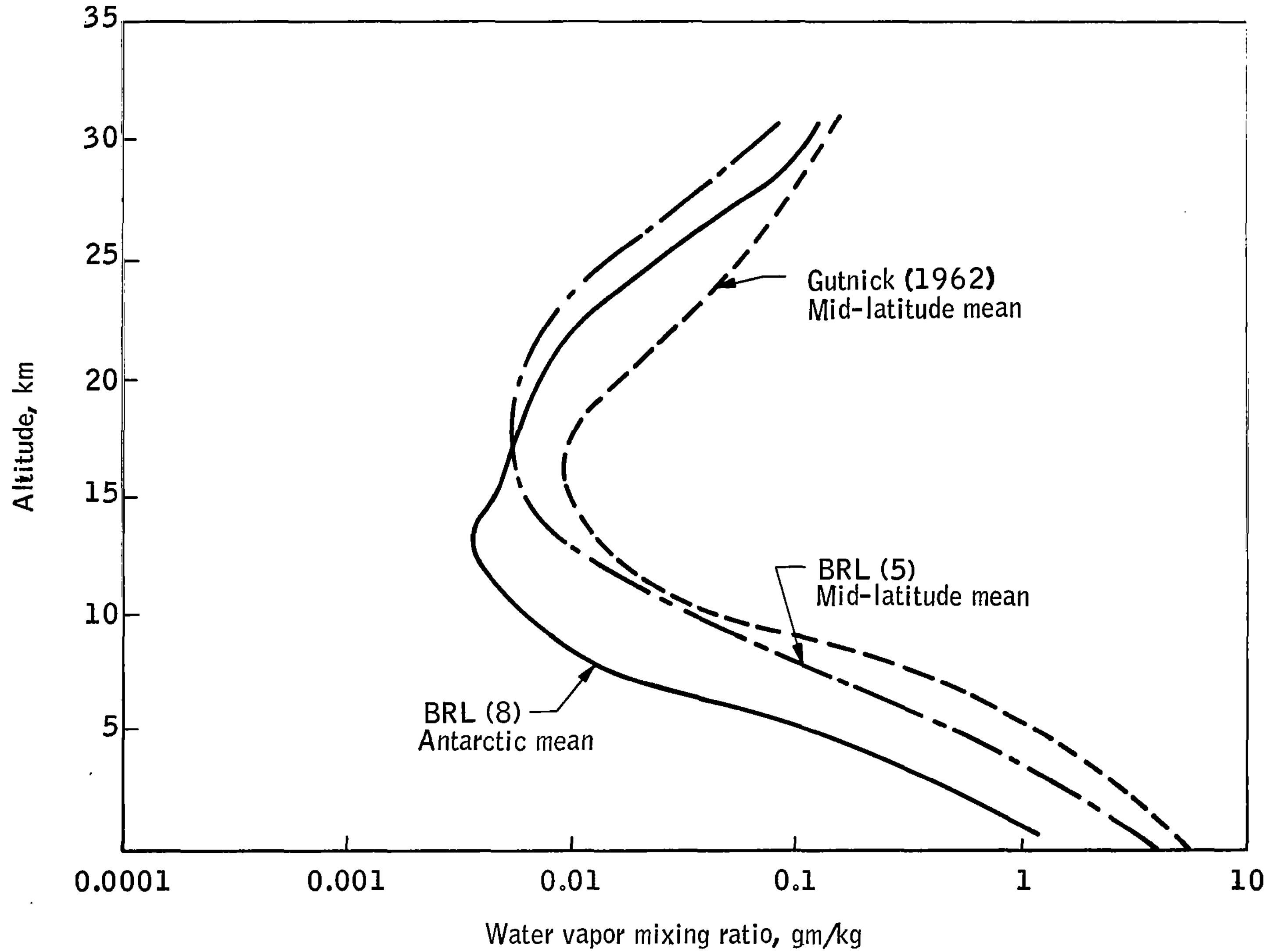

Figure 8. Water Vapor Mixing Ratios versus Altitude

Air often reaches its dew point by cooling caused by contact with the radiatively cooled surface of the Earth, or more often, by being lifted and cooled through thermodynamic processes.

Clouds may exist in the atmosphere from the surface to about 25 kilometers. This excludes the rare noctilucent clouds, which form at heights around 80 kilometers. Preferred regions exist for tropospheric clouds in both hemispheres.

Cloud distribution.-- The meteorological satellite, introduced by Tiros I in 1960, has brought a revolution to our knowledge concerning clouds. Observations previously had been confined to populated areas or those traversed by ships and airplanes. Observations that were made were usually quite sketchy, if not inaccurate, except perhaps in France, where Schereschewsky and Wehrle (ref. 20) made excellent observations, and persuaded the French meteorological service to make observations and charts superior to those of most other countries.

Figures 9 and 10 show cloud systems and cloud cover in the Northern and Southern Hemispheres, respectively (ref. 21). Solid black indicates overcast areas, heavy stipling areas of broken clouds, sparse stipling scattered clouds, and clear areas are left blank.

Meteorological satellites have provided a wealth of new information by observing not only entire cloud systems but also by observing temperatures of the cloud tops. These temperature observations enable the approximate height of tops to be determined by relating observed radiation temperatures to model atmosphere temperatures or through comparison with radiosonde soundings.

Cloud Systems.-- Early satellite observations by Tiros I and II confirmed and added to the basic models of cloud systems that Schereschewsky and Wehrle had put forth. Many cloud systems were seen to possess spiral-shaped clouds, or cloud vortexes, near regions of low pressure and in regions of maximum vorticity. Thought a rarity at first by many investigators, it is now known that about seven major cloud vortex centers associated with major low pressure centers usually exist in the Southern Hemisphere (ref. 22) and slightly more than that number in the Northern Hemisphere, where the presence of so much land mass breaks large circulations into smaller ones. Further, most of these large cloud vortexes are associated with long, trailing bands associated with frontal regions, commonly known as major bands (ref. 23). Major bands are on the order of several thousand kilometers long, and extend from vortex centers in high latitudes (on the order of 60°) to the tropics (on the order of 10-20°). The bands are commonly quite thick and wide in the middle latitudes, and extend vertically to the region of the tropopause.

Frequently, waves will form along these vast bands (ref. 24), often with a new vortex center appearing along the body of the band. Such new centers are commonly born in favored areas such as in the region of Cape Hatteras.

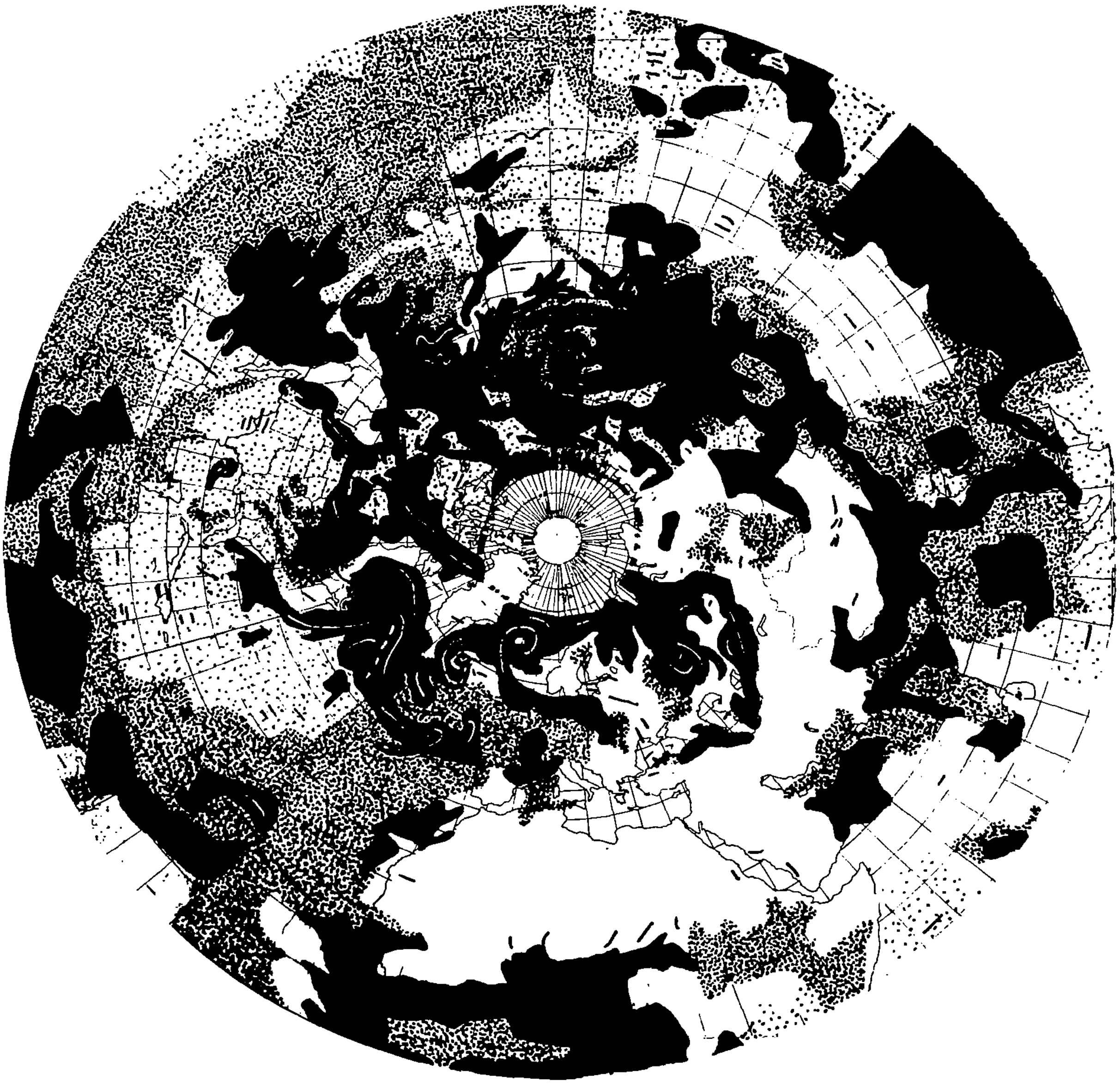

Figure 9. Northern Hemispheric Clouds, 22 July 1965
[From Ref. 21]

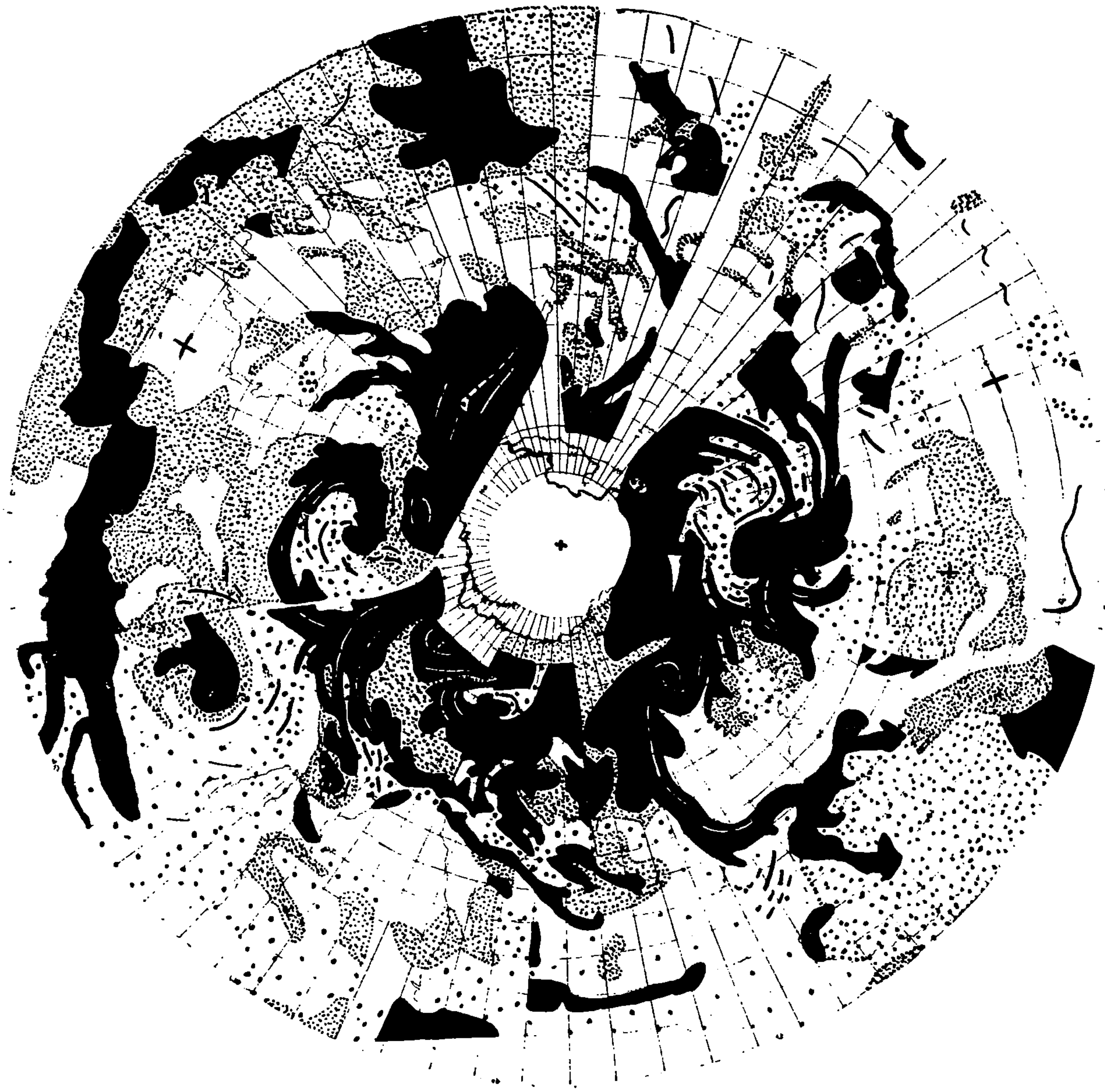

Figure 10. Southern Hemispheric Clouds, 15 February 1965
[From Ref. 21]

Major bands first appear in regions where southerly flow begins as the result of a perturbation in the zonal flow in the troposphere, i.e., between ridge lines to the east and trough lines to the west. This region is one of characteristically upward isentropic flow and maximum cyclonic vorticity advection. The major band, encouraged to grow by these occurrences, and further fed by the latent heat of condensation, finds its upward extent governed only by the stability at and above the tropopause. The life-time of a typical major band is on the order of 10 days to two weeks. When land, and especially mountains are encountered, the major band is often distorted into a barely recognizable pattern. Thus, such bands in the southern hemisphere are more regular in their pattern than northern hemisphere bands, and have a less involved life history. Typically, major bands in the Southern Hemisphere are born in the South Atlantic Ocean east of Argentina, gain size and strength as they make a complete circuit around the southern ocean, and then become broken as they enter the Andes Mountains of Chile (ref. 22). Cloud vortexes at the poleward extent of the major bands usually are centered about 1000 kilometers off the coast of Antarctica.

In the Northern Hemisphere, the major bands are predominantly smooth over the oceans, although they also tend to be smooth over land areas in the summer. Few survive the passage over the mountains of Europe where the terrain distorts them, and the desert of North Africa, where their moisture source is cut off. The portions of the major bands which drift into the deep tropical latitudes are usually quite narrow, and become oriented east-west before they slowly die. The tropical portion of the band usually outlives the remainder. Thompson, Cronin, and Kerr (ref. 25) have followed such bands into the deep tropics, and have observed instances where several bands existed while separated by a few degrees of latitude. In the tropics, the bands are commonly composed of convective clouds which perhaps get extended life from the great amount of latent heat of condensation available.

Since the mid-latitude portions of major bands are usually bounded at the top by the tropopause, they are quite cold, and radiation data show that the tops are at or near the tropopause temperature. Numerous investigations show this, e.g., Rutherford (ref. 26) who found temperatures lower than 240°K along major bands in May between 40°S and 50°S. Wexler (ref. 27) showed temperatures below -40°C (~230°K) along a band over the United States, also in May. Actual temperatures were probably slightly colder, due to the poor resolution of the Tiros II 8-12 micron sensor, from which the information was taken.

Since major bands are associated with frontal systems, it can be expected that where cold air is flowing southward behind them, convective clouds will form associated with the resulting instability of the lower layer of the troposphere. The satellites have shown this to be the case. These clouds form in long lines behind the major band, and often also form in long bands transverse to the cloud lines. Depending on the degree of instability, these clouds may cover either a small portion or a major portion of the Earth behind the band. These clouds often dissipate at night over the land areas, where solar heating has enhanced their development during the day. Usually their bases and tops are quite low, although in some instances where instability is great, they may develop into small cumulonimbus. Over large portions of interior North

America and Asia in the winter, these clouds are often very low, and bring overcasts over extensive regions.

In the vicinity of the equator, and usually just north of it, a broken belt of clouds about five degrees wide and extending to the tropopause is usually found encircling the Earth. This has been dubbed the "Intertropical Cloud" by researchers who prefer to avoid reference to its alleged association with the so-called intertropical convergence zone model which has held wide, if not reputable, currency in the past few decades. Whether or not the cloud belt can be explained in terms of the intertropical convergence zone model is perhaps secondary in importance to the fact that this cloud system extends to heights of 20 to 25 kilometers, owing to the high tropopause found in the tropics. Satellite 8-12 micron window observations find very low temperatures along this belt, confirming its great extent. This belt of clouds is a persistent feature of the Earth's cloud assemblage 365 days a year.

Preferred regions for clouds. -- There are regions of the Earth which are nearly always devoid of clouds. These are the areas where the air is much too dry, and/or where there is persistent descending motion. These areas include the Sahara, the Gobi, and other deserts, as well as a vast region of the tropical central South Pacific Ocean which has been called the "Great Ocean Desert".

Over the Antarctic continent, away from the coastline, reports that clouds of any thickness seldom occur are due more to fact that to lack of contrast between ice and snow. Biter (personal communication) has pointed out that most clouds well inland over the continent are usually composed of ice crystals, and that the average sky cover by clouds in some areas in some parts of the year is as low as 10 percent.

In some cloudy areas, such as under the subtropical highs off the coast of California, clouds seldom reach more than one or two kilometers above sea level. These clouds are due to the passage of cold air over warmer water, but their vertical extent is held in check by the stability generated by the warm descending air above them. The extreme cloudiness is caused by the fact that they spread out beneath the inversion created by the descending process. In such areas, many interesting small cloud vortexes form. They are not, however, of as much concern to us as are the high clouds of the major bands and the intertropical cloud.

For the sake of completeness, mention should be made of the crazy-quilt cumulonimbus clouds in the tropics which penetrate to the tropopause, but which seldom cover very much of the Earth.

The final clouds of importance are those associated with tropical storms and hurricanes. In the tropical storm, cumulonimbus frequently penetrate to the tropopause and their ice crystal mantles cover large areas, up to perhaps 800 kilometers in diameter. They show up as very cold spots in the window channel, and on the Nimbus II satellite, are even seen on the 15 micron CO_2 channel as shown in the section on experimental programs of this report. Full-fledged hurricanes are usually capped by a stable layer a few kilometers below the tropopause, so their topside temperatures are not as low. Hurricanes which hit land, especially mountainous regions, are the exception. The resulting forced additional convergence raises their extreme height to the tropopause, but this convergence also weakens them and turns them back into tropical storms.

The satellite promises to give us an excellent climatology of cloud cover over the Earth in the next decade, but certain limitations exist. For one, the satellite cannot tell us what is beneath the clouds - whether or not they are solid to their base, or in layers. Most cloud systems are probably in layers. Evidence of this comes from an investigation performed by the Staff Members of the Weather Forecasting Research Center at the University of Chicago (ref. 28). Their investigation revealed that layers of clouds in cyclones are the rule rather than the exception.

Also, the varying transparency of ice crystal "clouds" causes difficulty in determining the "cutoff" point between what is and what is not a cloud. Pilots often see ice crystal clouds when in the air, while observers on the ground cannot see them. In the visible part of the spectrum, ice crystal clouds easily seen from the ground are not visible to the satellite.

Cloud models, such as that of Watson and Shenk (ref. 29) must continue to serve climatology needs until the satellite yields an adequate sample.

Generally, the average amount of Earth free of all clouds is approximately 40 percent, while the amount free of all clouds but cirrus too thin for a satellite to see approaches 60 percent. About seven percent of the Earth is covered by opaque clouds at altitudes in excess of 10 kilometers at any given time, with less than one percent covered by opaque clouds in excess of 20 kilometers.

THE THERMAL STATE OF THE ATMOSPHERE

The intensity of radiation from a body is a function of its emissivity and the temperature of the body. If the emissivity is unity, then the body is black, and the intensity of radiation at 15μ is approximately proportional to the fourth power of the temperature by Planck's formula. Hence, changes or variations in temperature that are not large can cause large changes in radiation intensity.

Temperature can change in the atmosphere by radiative heating and cooling, by warming and cooling through contact with the Earth, by the release of latent heat of condensation which causes heating, and the loss of heat through evaporation and freezing which causes cooling; and by air changing its altitude to warm or cool adiabatically by sinking and rising, respectively.

In the troposphere, all of these processes operate to change the atmospheric temperature, while in the stratosphere, changes are wrought mainly by radiative processes on ozone, as discussed above, and by rising and sinking because of stratospheric circulations.

Tropospheric Temperatures

The temperature of the troposphere may vary from about -87°C to +57°C. These extremes occur at the surface, with the warmest temperatures occurring over the low-latitude deserts and the coldest over the Antarctic ice pack.

The general change of temperature with altitude can be seen in the model atmospheres presented previously, but the general changes often vary drastically from those seen in migrating cyclones and anticyclones. Smallest variability of tropospheric temperatures with altitude occur in the tropics, but large deviations occur in the middle and high latitudes.

Large fields of very warm temperatures throughout the troposphere often occur in the large, warm anticyclones in which air is sinking and warming adiabatically. Large fields of very cold temperatures throughout the troposphere are common in intense cyclones, or low-pressure regions, where the air is rising and is being cooled nearly adiabatically. Heating occurs, especially in the lower layers, because of the release of latent heat by condensation and freezing of liquid water within the system. The heat gained is often lost by the cyclone, however, if the condensed water evaporates rather than falling out as rain or snow. Further, at cold temperature (below -10°C), the heat gained by condensation is virtually negligible.

Over the oceans, especially the tropical oceans, much heat is lost in the lowest part of the troposphere by evaporation. This heat is then released in the middle troposphere, however, through condensation and freezing. Thus, the inter-tropical cloud, and the sundry other convective clouds in the tropics and in the summer hemisphere which release their condensed H_20 to the Earth as rain, act as agents in transporting energy aloft. Much of this energy is advected aloft to higher latitudes by tropospheric circulations. Much of the heat gained in the tropics is also released to the higher latitude troposphere through clouds which form and release their liquid and solid content as the air moves upward and poleward "isentropically".

The clouds themselves preserve the thermal energy of the Earth's surface and atmosphere below them. Radiation directed upward is returned downward by the opaque clouds. Thus, the radiative energy, going to outer space where a cloud is present, is coming from the cloud top, and the Earth radiation below the cloud cannot escape. Where it is clear, that is, where clouds do not cover the Earth, radiative energy is being released rapidly to space. Since radiation intensity is proportional to approximately the fourth power of the absolute temperature, regions of high opaque cloudiness are conserving energy, while regions of no clouds are releasing energy.

Stratospheric Temperatures

The lower stratosphere is generally devoid of clouds, and is so cold and dry that latent heat considerations are not significant. The warmth that is in the stratosphere is mainly due to the absorption of ultraviolet by ozone in its upper portion, and to the advection over the winter pole by warm air from the tropical regions.

Adiabatic warming and cooling also causes certain parts of the stratosphere to become warmer and cooler. Until the past decade, little was known of stratospheric circulations which produce adiabatic changes. The past decade, of course, has seen frequent penetration of the stratosphere by balloons and rockets, and various investigators have been able to chart the movement of isobaric surfaces and their accompanying temperature fields.

It is now known that the stratosphere undergoes an annual reversal in wind flow in both hemispheres in the middle and high latitudes. Labitzke (ref. 30), Webb (ref. 17), Reed (ref. 31), Sawyer (ref. 32), Finger, Mason, and Corzine (ref. 33), Nordberg and Stroud (ref. 7), and Craig and Herring (ref. 34) are among investigators who have studied the stratospheric circulation. This wind reversal has important consequences on the temperature field in the stratosphere.

According to Webb (ref. 17) the stratosphere in general has a west wind over the middle and high latitudes of both hemispheres in March, with a changeover to generally easterly winds in the Northern Hemisphere beginning in April. This situation maintains itself until September, when the Northern Hemisphere easterlies die out, and once again both hemispheres have westerly winds. About 40 days after this, the Southern Hemisphere stratospheric winds switch to general easterlies, while general westerlies persist in the northern hemisphere until early spring, when the Southern Hemisphere stratosphere reverses itself to west winds. As a result, both hemispheres are then in a westerly stratospheric circulation, and this continues for about 40 days to the Northern Hemisphere reversal, where the cycle is again repeated.

The easterly winds are associated with a high over the pole, the westerly winds with a low. Therefore, the time of the east wind corresponds to warm stratospheric temperatures, and the time of the west wind corresponds to a cold stratosphere.

The onset of the reversal of the wind field from westerly to easterly is rather sudden, with the result that the stratosphere changes its temperature rather abruptly. Early investigators were rather startled by these temperature changes. Meteorologists became greatly interested in the stratosphere, which up to then had been considered an inactive region of the atmosphere. The warming effect was given the name "sudden" and "explosive" warming by the early workers in these stratospheric investigations.

Although the stratospheric easterlies and the westerlies possess an appreciable degree of consistency after they are once established, certain characteristic perturbations occur. One of the most remarkable of these is the Aleutian Anticyclone, a high which appears in October and persists in the stratosphere even through the winter. This high tends to oscillate between Eastern Siberia and Central Canada in the winter, bringing very warm temperatures to those regions as it enters. Occasionally it disappears, but then re-establishes itself soon after.

The months of February through March are periods of major shifts in stratospheric cyclones and anticyclones in the Northern Hemisphere. These are the months before the springtime wind reversal.

Temperatures associated with stratospheric cyclones are as low as -75°C (at 10 millibars or about 30 kilometers) while temperatures at the same altitude can run as high as -25°C. Because of the persistence of the Aleutian Anticyclone, the temperature range over the year in the stratosphere at 10 millbars over the Aleutian Islands is on the order of only 20°C. Central Canada (Fort Churchill region), by contrast, experiences annual ranges of about 40°C at 10 millibars, reflecting the alternate dominance of that region by the winter polar low and the winter Aleutian Anticyclone.

Ridges and troughs, associated with warm and cool stratospheres exist elsewhere around the hemisphere. Often a warm ridge will appear in the stratosphere over Europe. Labitzke (ref. 30) has studied ridge and anticyclone patterns over Europe and North America over a period of years, and finds that there is a stratospheric pattern preceding tropospheric changes on the order of ten days.

Labitzke also found that if explosive warming over Central Canada occurred before warming in Europe, migrating stratospheric anticyclones would travel eastward across the Atlantic. If explosive warming occurred over Europe earlier in the year than over Central Canada, migrating stratospheric anticyclones would move westward from Europe to North America. Further, the European warmings would be followed by formation of blocking anticyclones in the eastern Atlantic Ocean about 10 days after the onset of the explosive warming. Later, Labitzke and Van Loon (ref. 35) found the same 10-day relationship in an investigation of the Southern Hemisphere at Campbell Island (52°S, 116°E).

Even more significant, Labitzke found that every other year (1958, 1960, 1962, 1964) the initial explosive warming in the stratosphere would start over Europe, and every other year in between (1957, 1959, 1961, 1963) they would start over Canada. Labitzke suggests that there is a connection between these events and the 26-month cycle (or biennial) in the wind and temperature field of the tropical stratosphere.

Nordberg, Bandeen, Kunde and Warnecke (ref. 36) and Merritt (ref. 2) have used Tiros VII radiation data to study stratospheric temperatures. Nordberg and his co-workers observed warming and the development of the Aleutian Anticyclone in 1963, and the development of a sudden warming over the Caspian Sea in January 1964. The Caspian warming was on the order of 20°C, and lasted for about one month. Merritt also studied stratospheric temperatures in vicinity of the Aleutian Anticyclone.

<u>The 26-month or biennial cycle in the tropics</u>. -- Previous to Labitzke's work, investigators found evidence of a 26-month (or possibly biennial) cycle in the stratospheric winds in the tropics. This cycle is represented by an east wind in the tropical stratosphere for 26 months followed by 26 months of west winds. This applies to the tropics in both hemispheres simultaneously. Features of this cycle include the interesting fact that the first wind reversal appears at the highest altitude of the radiosondes (about 31 kilometers). The

wind then begins to reverse successively downward at the rate of 1 kilometer per month, so that it takes about a year for the reversal to descend all the way to the tropical tropopause (about 18 kilometers).

The cycle is not exactly 26 months but varies between about 21 and 28 months. Thus, some have suggested that until another decade goes by, the cycle cannot be established as a two-year (24-month) cycle rather than a 26-month cycle.

However, this cycle is not particularly serious with regard to temperature oscillation. The temperature cycle is only about 2°C in the vicinity of 25 to 30 kilometers altitude at the equator and is less poleward at the same levels and at lower levels along the equator. The temperature oscillation progresses downward with the wind at 1 kilometer per month. There is a reversal and minimum in magnitude to the temperature oscillation around 15 to 17 degrees north and south, but the oscillation increases in magnitude poleward of these latitudes and reaches a maximum of about 1°C at higher levels (20 to 30 km) around 25°N to 30°N. These changes are, of course, much less than temporal changes in the diurnal and day-to-day scale, even in the tropics. However, since the oscillation at the equator is in opposite phase to the oscillation in the vicinity of the two tropic lines (Cancer and Capricorn), a 3°C gradient may be set up which alternates in direction every two years or 26 months.

CARBON DIOXIDE VARIATIONS

The concentration of atmospheric carbon dioxide is of considerable importance to the horizon locator problem. When scanning the horizon with a satellite mounted detector, sensitive to radiation in the 14 to 16μ CO_2 band, the measured radiance emitted by the atmosphere is intimately related to the concentration of carbon dioxide. Also, the observed horizon radiance profile would be affected by variations in the concentration of carbon dioxide. Therefore, it is important to review our present knowledge of the concentration of atmospheric carbon dioxide and its variation with time and space.

In the following discussion, available observations of the variations of carbon dioxide are reviewed in terms of diurnal variations, monthly and yearly variations, latitudinal variations and variations with height in the atmosphere. Based on these observations, a standard vertical profile of carbon dioxide concentration between the surface and 90 km is presented. Briefly, observations indicate that the average concentration of carbon dioxide is about 0.0314 percent by volume, i.e., 314 parts per million (ppm); that, above a height of one kilometer, the average deviations about the mean concentration is, at all levels, less than ±3 percent; and that the concentration generally decreases slightly with height in the atmosphere.

Diurnal Variations

The diurnal variations of the concentration of CO_2 in the atmosphere are due to exchange of CO_2 between the atmosphere and the biosphere. In particular, vegetation plays a major role in this exchange. The CO_2 exchange of plants depends on the time of day because plant photosynthesis involves assimilation and respiration processes which depend on the amount of sunlight, water, and CO_2. The concentration of CO_2 near vegetation has a maximum near dawn and a minimum near noon (ref. 37). Observations indicate that the range of variation depends upon the type of vegetation. At a height of 8 meters (m) above a forest, the diurnal variation is about 38 ppm, about 12 percent of the lowest concentration of CO_2, 320 ppm (refs. 38, 39, and 40). It should be mentioned that the above measurements are taken a few meters above the vegetation. Because of different mixing processes, the concentration inside of the vegetation can be 20 to 50 ppm higher, while the concentration far above the vegetation would be the same as that of the free atmosphere. Figure 11 illustrates the diurnal variation of CO_2 at different heights above vegetation.

Little information in the literature is available on the diurnal variation of the CO_2 concentration above vegetation at heights from 100 m to the free atmosphere. Qualitatively, one would expect strong vertical mixing during the daytime, owing to the steeper temperature lapse rate, which would lead to a CO_2 concentration larger than the mean value. During the night, converse would be true. A temperature inversion would tend to restrict the vertical exchange leading to smaller concentrations of CO_2. No theoretical treatment of this problem is presently available.

Observations of the diurnal variation of atmospheric CO_2 for different months at Mauna Loa Observatory in Hawaii are shown in Figures 12 and 13. The observatory is located 30 km away from any vegetation, but is under the influence of a sea breeze circulation during the afternoon, which is correlated with the observed minimum concentration at this time.

The average daily changes, in general, have a pattern similar to that of Figure 11. That is, the maximum and minimum concentrations in a day are found during the forenoon and afternoon, respectively. However, the nocturnal bursts, a general increase in concentration after sunset, are less regular than the dip in the afternoon. The general trend of daily extremes shifts slightly to later times from September to March. The largest range is found in September and the smallest range is found in February. The annual average of the diurnal variation of atmospheric CO_2 at Mauna Loa is shown in Figure 14.

The nocturnal burst is related to the south wind, by which the volcanic CO_2 is brought to the station by down-slope winds from the summit of the mountains. The afternoon dip is mainly due to the sea breeze circulation effect in which CO_2 is taken up by the vegetation on the lower slope before reaching the observing station.

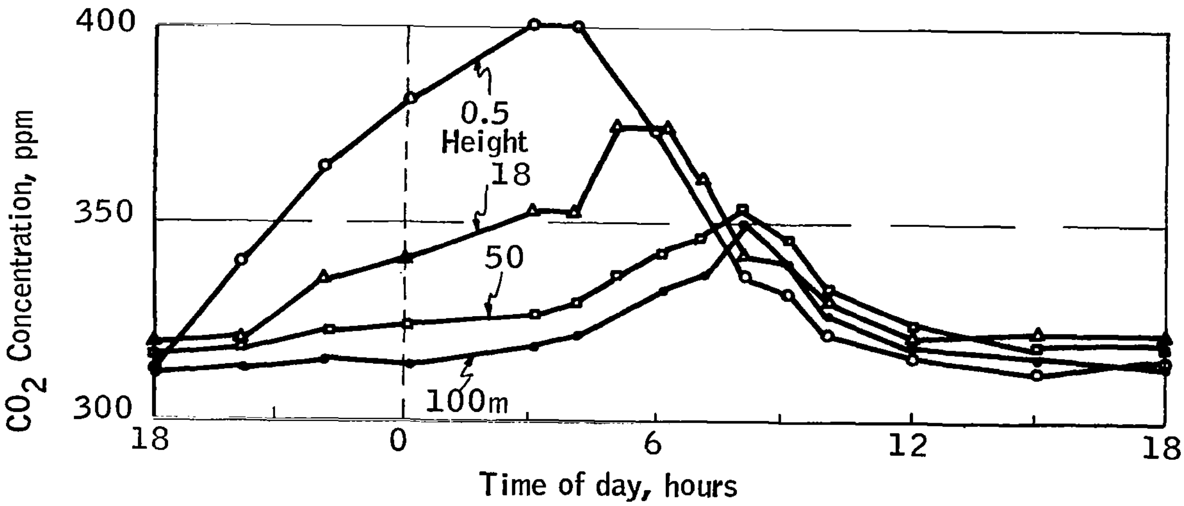

Figure 11. Average Daily Variation of CO_2 Concentration at Different Heights Above Vegetation [From Ref's. 39 and 40]

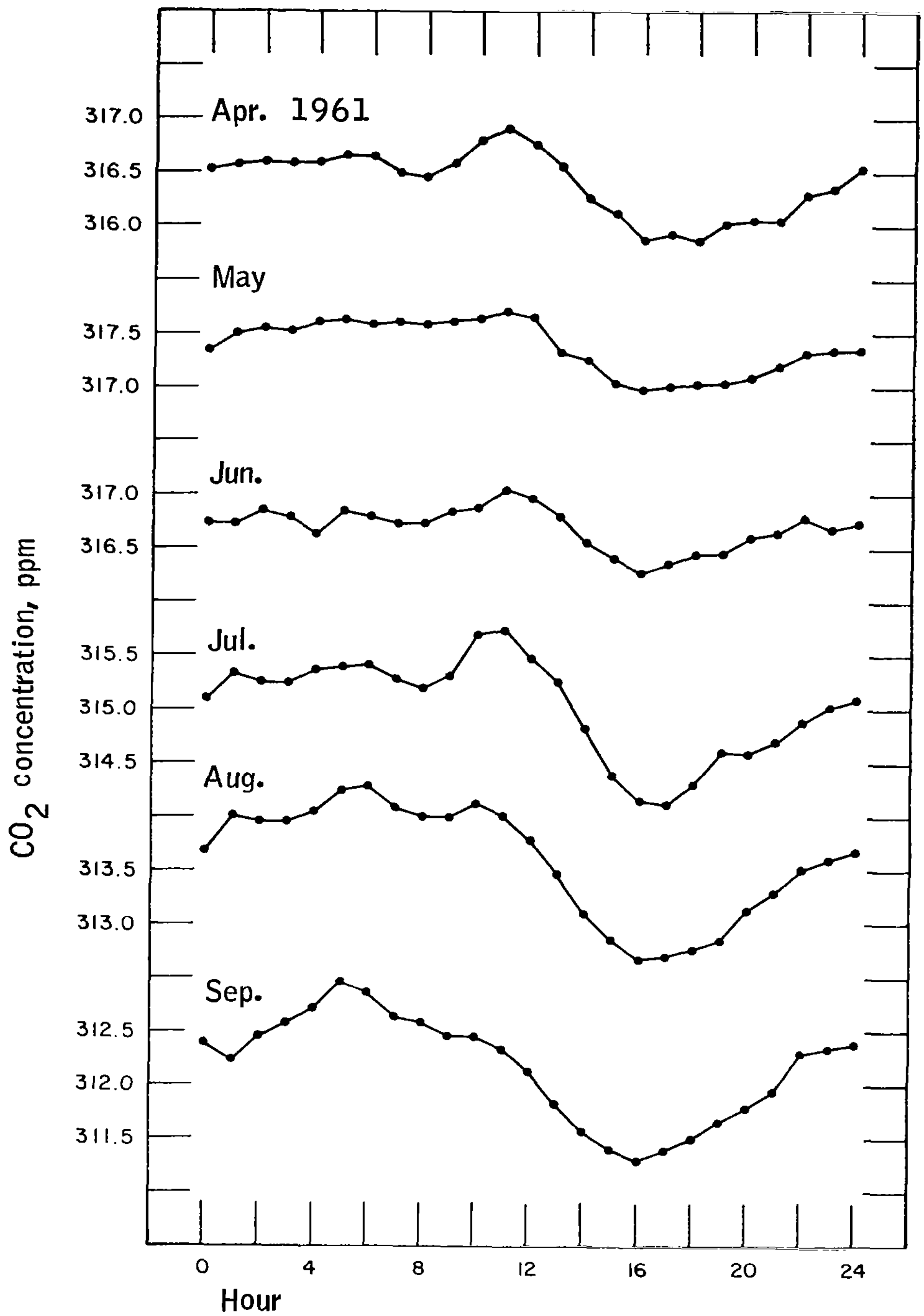

Figure 12. The Diurnal Variation of Atmospheric CO_2 at Mauna Loa Observatory in Hawaii, October 1961 [From Ref. 41]

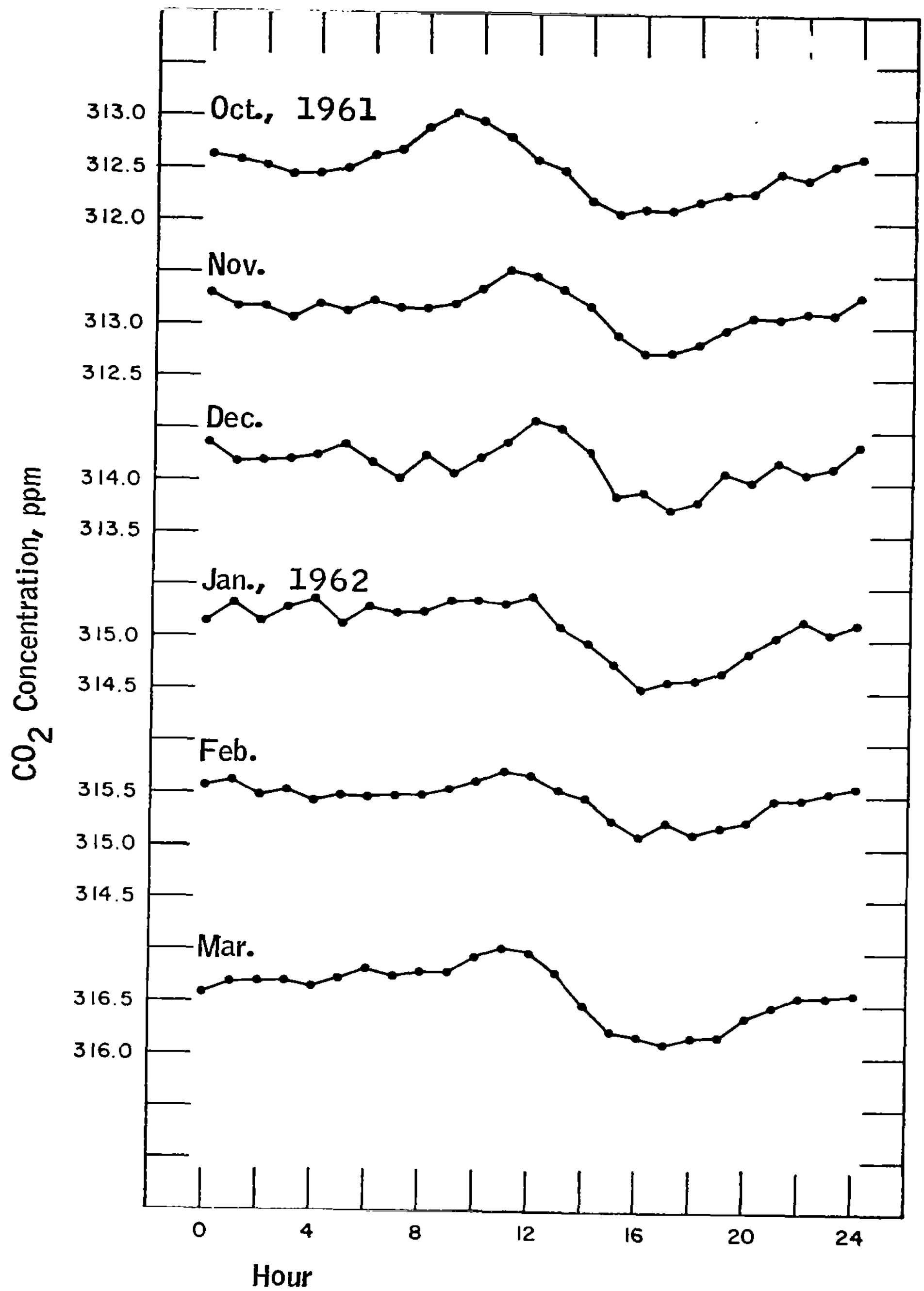

Figure 13. The Diurnal Variation of Atmospheric CO_2 at Mauna Loa Observatory in Hawaii, April 1961 [From Ref. 41]

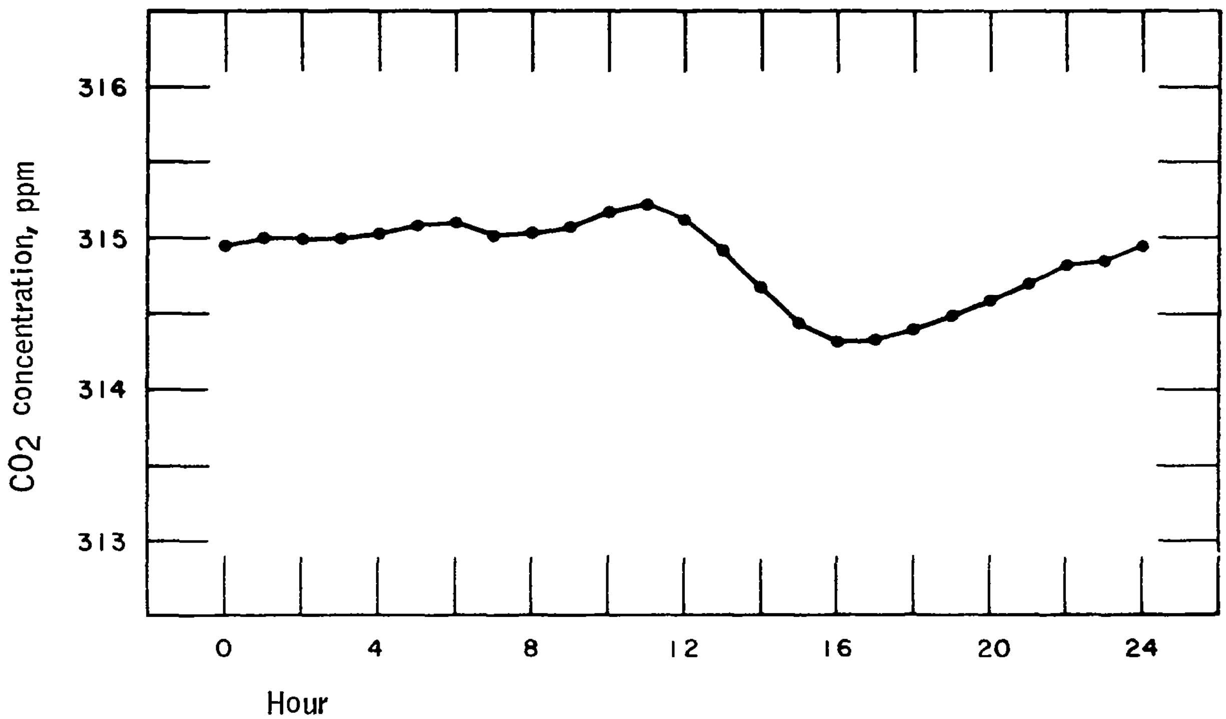

Figure 14. The Annual Average Diurnal Course of Atmospheric CO_2 at Mauna Loa Observatory
[From Ref. 41]

Annual Variations

The monthly and yearly variations on the daily maximum and minimum CO_2 concentrations in the open air close to the top of a vegetation unit were measured and analyzed by Huber (refs. 40 and 42) and Pommer (ref. 42) and are shown in Figure 15. The extreme maximum is about 440 ppm in July and the extreme minimum is about 300 ppm in November. The peak of the monthly average of the maximum is about August, and the lowest value of the monthly average of the minimum is in July.

The daily average concentration of atmospheric CO_2 at Mauna Loa Observatory in the course of 1963 is shown in Figure 16. The monthly average versus time for the period between 1958 and 1963 is shown in Figure 17. These observations also show that the annual maximums and minimums of the CO_2 concentration occur in May, and September-October, respectively. Based on these results, the rate of yearly increase of atmospheric CO_2 at the Observatory, presumably due to world wide combustion of fossil fuels, is about 0.68 ppm per year. The data collected from aircraft observations at 700 mb during 1960 and 1961 near Mauna Loa Observatory are compared with surface observations in Figure 18. The phase and magnitude at the 700 mb level during 1960 and 1961, in general, reveal the same characteristics as the observations at the surface.

The month to month variations of CO_2 concentration in the free atmosphere over the Northern Hemisphere were collected and analyzed by Bolin and Keeling. For illustration, these variations are shown in Figures 19 and 20. The maximum CO_2 concentration is detected in May and the minimum CO_2 concentration is detected in September. The monthly range at lower latitudes is smaller than the range at higher latitudes. The average range is about 7 ppm.

Latitudinal Variations

The variation with latitude of the annual average concentration of CO_2 is shown in Figure 21. Several features stand out. The highest values occur at equatorial latitudes, the lowest values at the poles. This is attributed to a net release of CO_2 from the oceans to the atmosphere at low latitudes. The Northern Hemisphere values are greater than the Southern Hemisphere values. This is due to the greater industrialization and attendant release of CO_2 into the atmosphere by fossil fuel combustion. A secondary maximum at 500 mb at middle latitudes of the Northern Hemisphere is probably the result of a concentration of industrialization at these latitudes. The total CO_2 range is only about two ppm -- from 313 ppm at the South Pole to 315 ppm at the equator.

The variation of CO_2 concentration with latitude and month of the year is shown in Table 6. These data are based upon CO_2 observations at 500 mb and 700 mb for the Northern Hemisphere and near the surface for the Southern Hemisphere. The seasonal variation increases with latitude from a range of about one ppm at the South Pole to about nine ppm at high

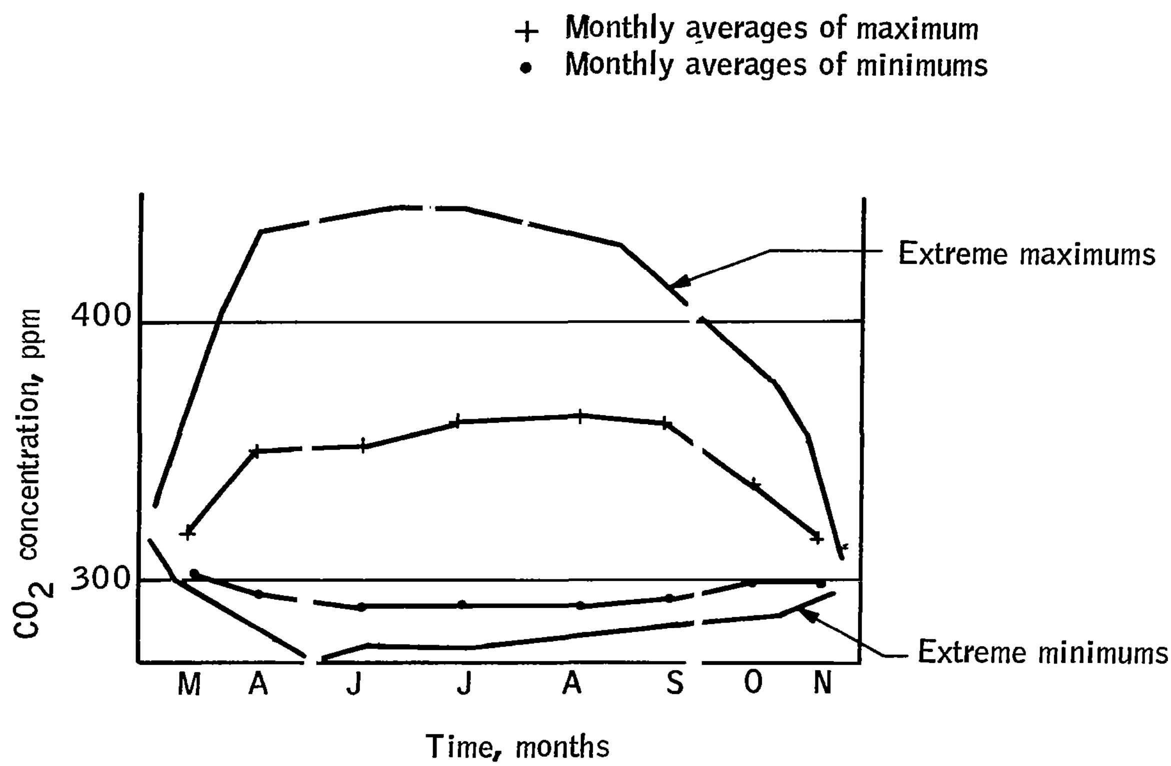

Figure 15. The Yearly Variation of Daily Maximums and Minimums of the CO_2 Concentration 18 m Above a Crop Field
[From Ref's. 40 and 42]

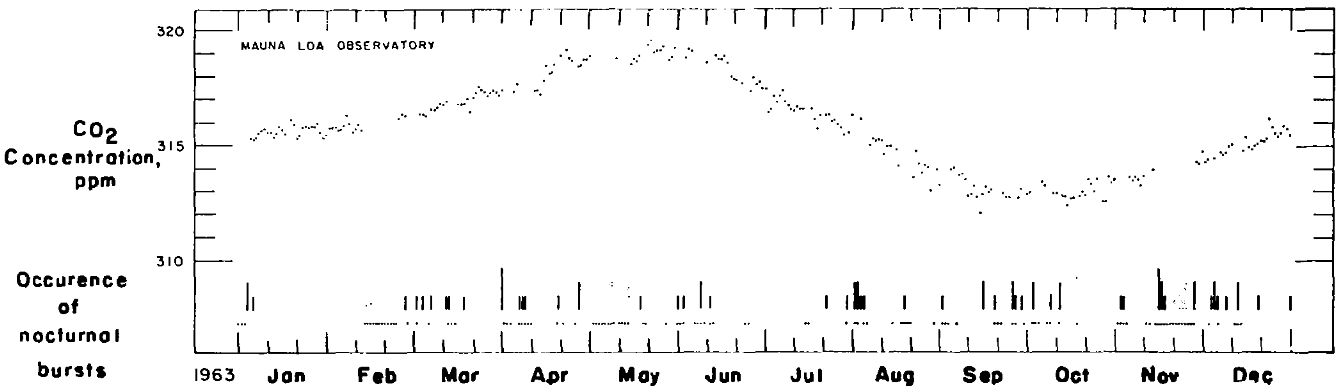

Figure 16. The Daily Average Concentration of Atmospheric CO_2 at Mauna Loa Observatory in the Course of 1963 [From Ref. 41]

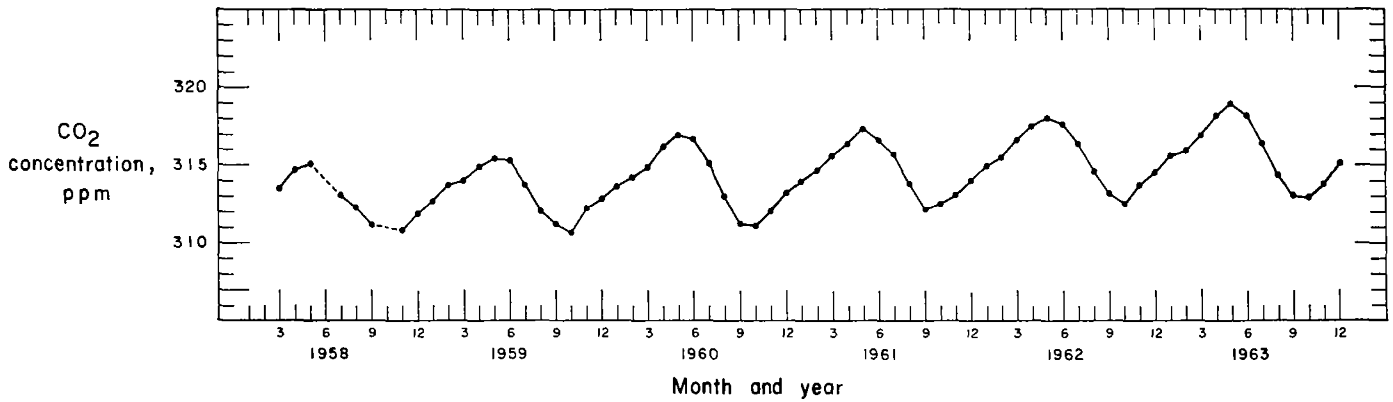

Figure 17. The Monthly Average Concentration of Atmospheric CO_2 at Mauna Loa Observatory versus Time [From Ref. 41]

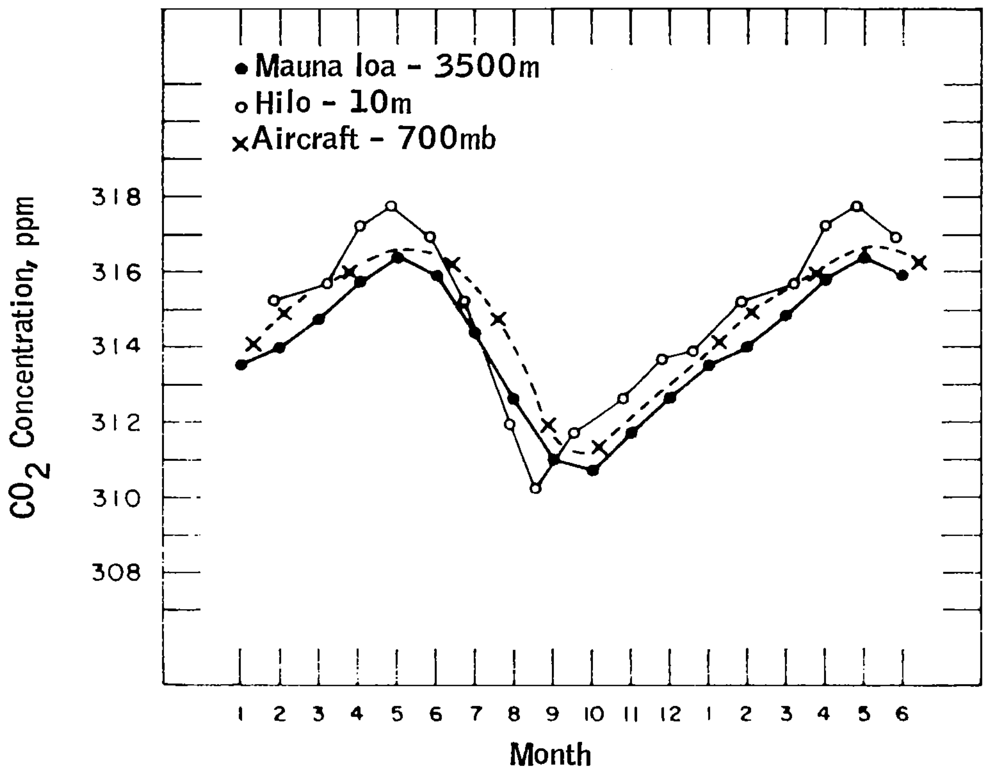

Figure 18. CO_2 Concentration at 700 mb Level Near Hawaii [From Ref. 41]

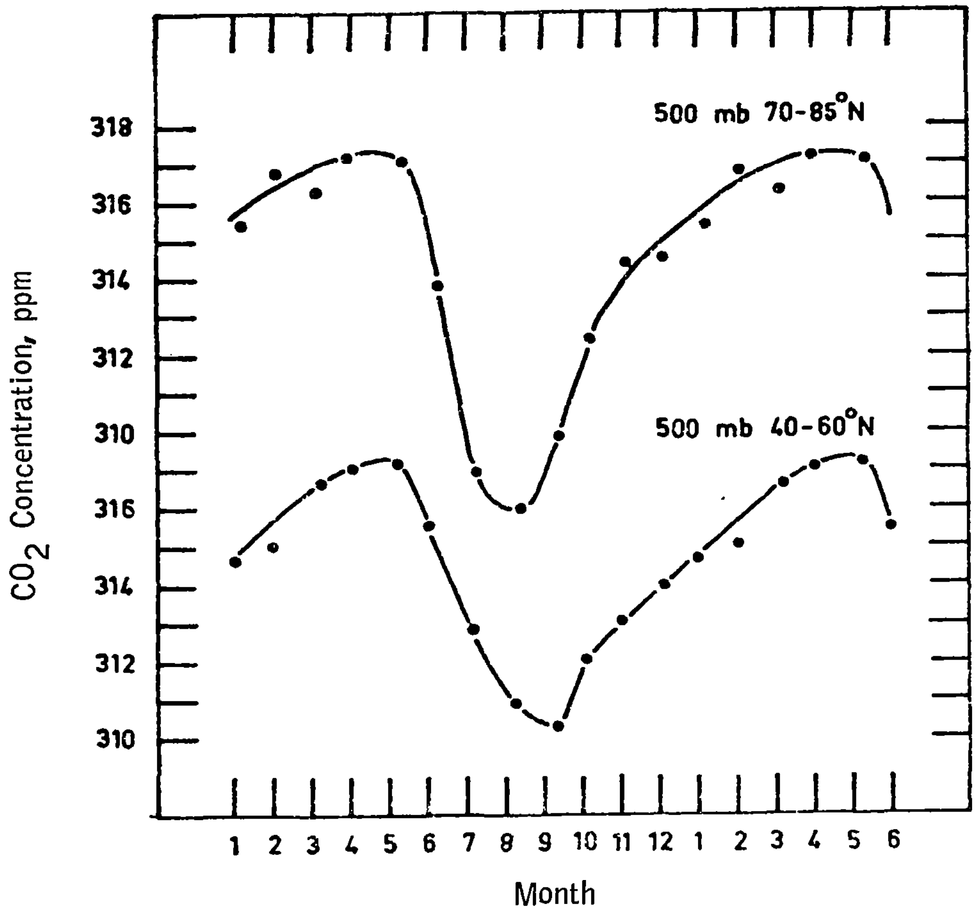

Figure 19. The Concentration of Atmospheric CO_2 at 500 mb Level and Latitudes Between 40 and 60°N and Between 70 and 85°N as Functions of the Month of the Year [From Ref. 43]

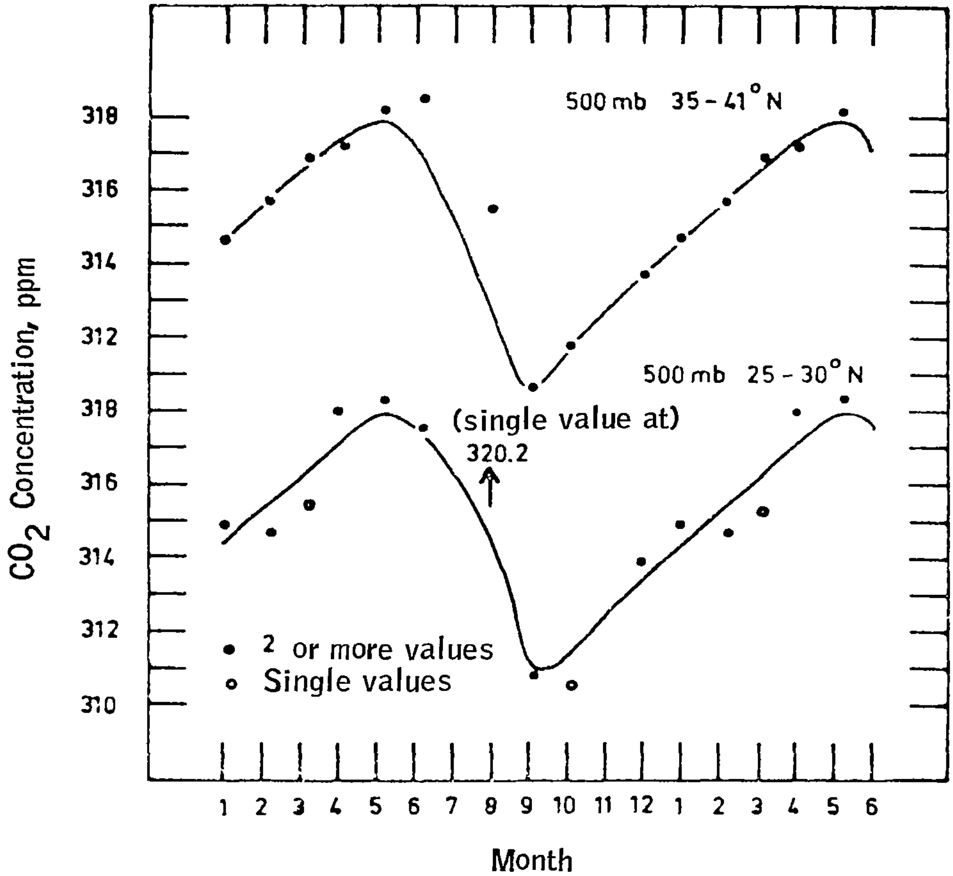

Figure 20. The Concentrations of Atmospheric CO_2 at 500 mb Level and Latitudes Between 25 and 30°N and Between 35 and 41°N as Functions of the Month of the Year [From Ref. 43]

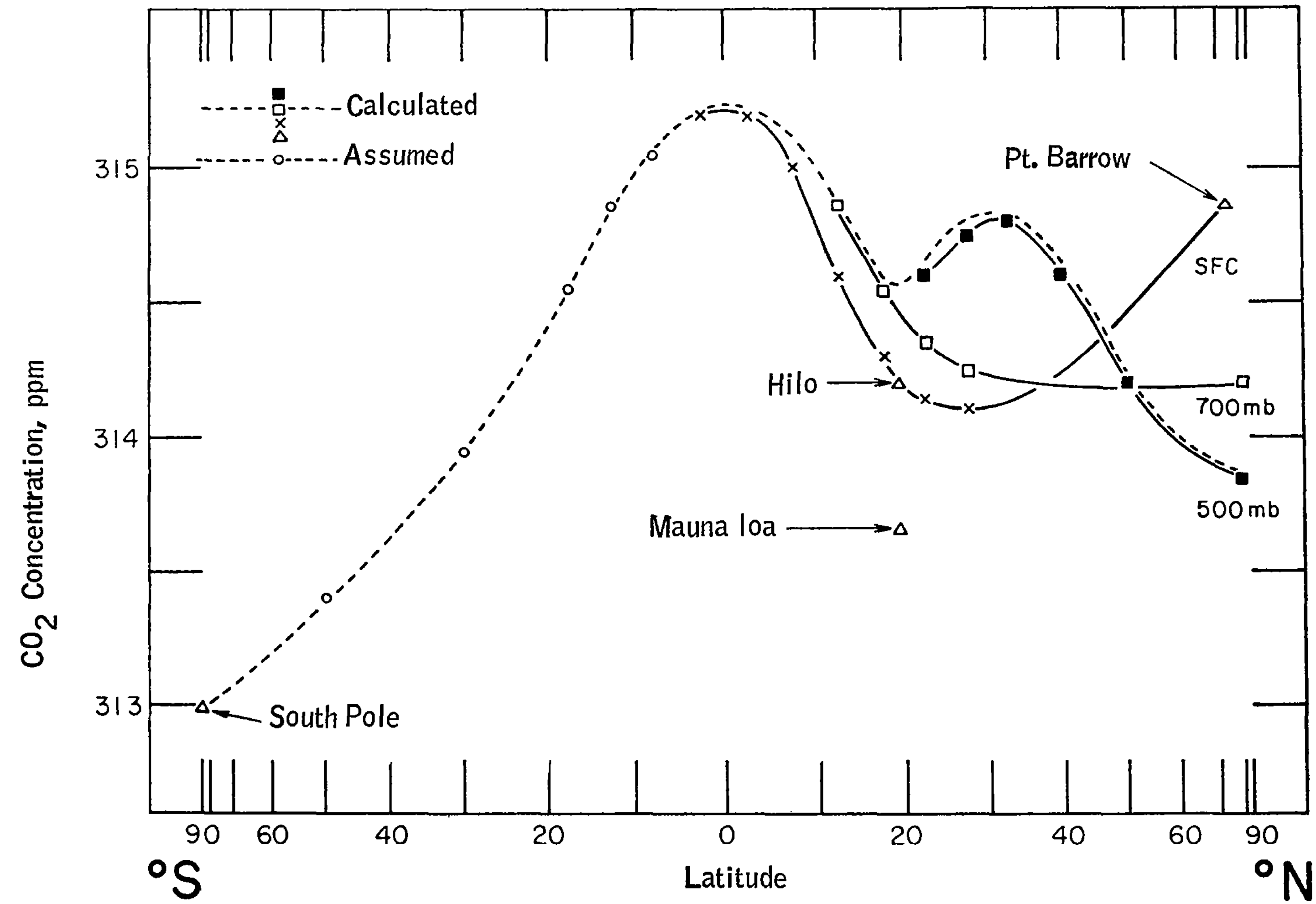

Figure 21. Annual Average Concentration of Atmospheric CO_2 as a Function of Latitude [From Ref. 43]

TABLE 6. - SMOOTHED AVERAGE VALUES OF THE CO_2 CONCENTRATION, ppm BY LATITUDE AND MONTH

[From ref. 43]

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
78.0°N	315.7	316.4	316.9	317.2	317.2	315.5	309.9	308.0	308.8	311.8	313.7	315.0	313.85
50.0°N	314.8	315.7	316.5	317.1	317.3	315.5	313.0	311.2	310.3	311.9	313.0	313.9	314.2
40.0°N	314.6	315.6	316.5	317.3	317.9	317.1	315.2	312.6	310.6	311.7	312.7	313.7	314.6
32.5°N	314.5	315.4	316.3	317.3	318.0	317.6	316.0	313.7	310.9	311.5	312.6	315.6	314.8
27.5°N	314.4	315.3	316.1	317.1	317.9	317.5	316.3	314.3	311.1	311.4	312.5	313.5	314.8
22.5°N	314.2	315.1	315.9	316.6	317.2	317.0	316.4	314.8	311.5	311.3	312.3	313.3	314.65
17.5°N	314.1	314.9	315.6	316.2	316.7	316.6	316.3	315.1	312.3	311.3	312.2	313.2	314.55
12.5°N	314.3	314.8	315.4	315.9	316.3	316.4	316.2	315.4	313.7	312.9	313.2	313.8	314.85
7.5°N	314.6	315.0	315.4	315.8	316.1	316.3	316.1	315.5	314.5	313.9	313.8	314.2	315.1
2.5°N	314.8	315.1	315.4	315.7	316.0	316.2	316.0	315.6	315.0	314.3	314.0	314.4	315.2
2.5°S	314.8	315.1	315.35	315.6	315.85	316.05	316.0	315.6	315.0	314.3	314.1	314.4	315.2
7.5°S	314.6	314.9	315.15	315.4	315.65	315.9	315.9	315.6	314.9	314.3	314.1	314.3	315.05
12.5°S	314.3	314.6	314.85	315.1	315.4	315.7	315.8	315.55	314.8	314.2	314.0	314.1	314.85
17.5°S	313.8	314.1	314.4	314.8	315.2	315.6	315.7	315.5	314.8	313.7	313.5	313.6	314.55
30.0°S	312.7	312.6	312.8	313.9	314.7	315.2	315.4	315.4	314.8	313.8	313.1	312.8	313.95
50.0°S	312.7	312.3	312.0	312.8	313.6	314.0	314.3	314.5	314.3	313.9	313.5	313.1	313.4
90.0°S	313.0	312.6	312.4	312.4	312.5	312.8	313.2	313.4	313.5	313.6	313.5	313.3	313.0
Average	313.37	314.67	315.11	315.66	316.09	315.94	315.16	314.22	312.49	312.43	313.28	313.89	314.51

latitudes of the Northern Hemisphere. This latitudinal variation of annual range of CO_2 concentration is due to the large amounts of land vegetation in the Northern Hemisphere. In the Northern Hemisphere the maximum CO_2 concentration generally occurs in late spring, and the minimum concentration generally occurs in late summer and early fall.

Since it it located far from industrial and vegetated areas, the South Pole is an excellent place to measure CO_2 concentrations for the purpose of deducing the long term atmospheric CO_2 increase due to combustion of fossil fuels on a world wide scale. Table 7 shows the results of CO_2 concentrations at the South Pole during the years 1958, 1960, 1961, 1962, and 1963. These data indicate that the mean atmospheric CO_2 concentration is rising at a rate of 0.68 ppm per year.

Vertical Variations

The overall vertical variations of CO_2 concentration are small except near the Earth's surface. From Figure 11, the maximum CO_2 concentration near the vegetation surface is about 400 ppm, and the corresponding CO_2 concentration at 100 m is only 330 ppm, the maximum difference being about 70 ppm. In the morning after the convection currents are established, there is a steady vertical transfer of CO_2 from the surface to higher elevations. This transfer diminishes and reaches a nearly steady-state condition in the afternoon, and results in a uniform CO_2 concentration with height. These results are believed to represent the vertical CO_2 variations for the planetary boundary boundary layer in a vegetation area.

Observations of the vertical variation of CO_2 concentration for other areas are available in limited regions of the Earth such as Scandinavia. These measurements are usually taken from either aircraft (refs. 43-45) or constant level balloons (ref. 47).

The annual average value of CO_2 concentration in Scandinavia from zero to three km is shown in Table 8. It can be seen that the CO_2 concentration near the surface is about 318 ppm, and the concentration decreases sharply to 314 at 0.4 to 0.6 km. From this level up, the change is rather small.

According to Bischof (ref. 46), the effects of the surface variation of the CO_2 concentration can extend up to tropopause. The temperature inversion at the tropopause tends to suppress any further vertical mixing. These observations from jet aircraft at a 10 km level indicate that the concentration in the stratosphere is about four ppm lower than the same height in the troposphere. It is important to mention that the observations are made in different locations on a flight path between Los Angeles and Scandinavia. Thus, the CO_2 concentration

TABLE 7.- MONTHLY AVERAGE CONCENTRATION OF ATMOSPHERIC CARBON DIOXIDE AT LITTLE AMERICA IN 1958 AND AT THE SOUTH POLE IN 1960 THROUGH 1963
[From ref. 43]

	1958		1960		1961		1962		1963	
Month	No. of days	Concentration ppm	No. of days	Concentration ppm	No. of days	Concentration ppm	No. of days	Concentration ppm	No. of days	Concentration ppm
January	7	310.86					11	314.70	31	315.23
February	27	310.77					27	314.48	28	314.97
March	31	311.05					30	314.26	29	314.57
April	30	311.35					30	314.31	18	315.31
May	30	211.68	4	313.40	13	313.56	28	314.36	30	315.64
June	30	311.86	30	313.08	30	313.56	20	314.48	25	315.58
July	31	311.92	10	313.56	31	313.64	28	314.48	28	315.60
August	30	312.61	18	313.53	23	314.03	31	314.80	24	315.64
September	28	312.90			19	314.34	28	315.21	22	315.74
October	29	312.81			18	314.96	29	316.01	16	316.30
November	3	312.25			30	315.07	16	316.23		
December					30	314.89	31	315.71		
Annual Mean		311.82		313.39		314.26		314.92		315.46

TABLE 8.- THE MEASUREMENT OF CO_2 CONCENTRATION IN SCANDINAVIA FROM ZERO TO THREE km
[From ref. 44]

Height km	Number of measurements	Lower and upper limit of CO_2 concentration ppm	Average of all values, ppm
0 -0. 2	51	306-340	318
0. 2-0. 4	31	300-329	316
0. 4-0. 6	19	305-327	314
0. 6-0. 8	10	304-325	314
0. 8-1. 0	13	305-322	315
1. 0-1. 2	12	309-320	131
1. 2-1. 4	5	309-318	312
1. 4-1. 6	12	309-321	316
1. 6-1. 8	9	308-319	312
1. 8-2. 0	4	307-319	315
2. 0-2. 2	7	308-320	314
2. 2-2. 4	--	---	---
2. 4-2. 6	3	310-319	315
2. 6-2. 8	4	310-317	312
218-3. 0	6	308-320	315
1. 0-3. 0	62	307-321	314

is about 314-315 ppm in the upper troposphere and about 310-311 ppm in the lower stratosphere. Also, because of the lack of convection and vertical mixing in the stratosphere, the time variation of the CO_2 concentration in the stratosphere wil be less than in the troposphere.

Between 15 and 30 km, observations of the CO_2 concentration were made from constant altitude balloons, and the results were analyzed by Hagemann, Gray, Jr., Machta and Turkevich (ref. 47). They conclude that the CO_2 concentration is about 312, 310, 313, and 310 ppm for the levels 15.5, 20.0, 24.8, and 28.0 km, respectively. The standard error of a single observation is about from 0.5 to 1.0 percent. The average value for all cases is about 311 ppm with an average deviation of less than one percent and a range of ±2 percent.

No measured CO_2 concentrations are available above 30 km. One would expect the concentration at higher elevations to be about the same as the value observed at 20 km.

Another aspect of the problem is the possible dissociation of the CO_2 molecule by ultraviolet radiation at 1600°A. Bates and Witherspoon (ref. 48) have considered this problem theoretically. Their calculations indicate that the lifetime of the CO_2 molecule is extremely long at 90 km, which suggests that dissociation effects are not important at this level. Above 90 km, the probability of dissociation increases with height. On the basis of these findings, the possible dissociation of the CO_2 molecule can be neglected in the horizon radiance problem.

Based on the results in preceding paragraphs a standard atmosphere profile of CO_2 concentration is constructed and is shown in Figure 22. The CO_2 concentration decreases somewhat from the surface up to 1 km level. The vertical variation in the troposphere and stratosphere are relatively small. Near the tropopause, which we assume is at 10 km, there is another small decrease of CO_2 concentration.

If we assume that the value of the CO_2 concentration at five km, 314 ppm, is representative of the average for the whole atmosphere, then the concentration at 0.1 km is about 2.2 percent higher than the average and the concentration at 30 km is about 1.0 percent lower than the average. A reasonable estimate of the average vertical variation of the CO_2 concentration about the mean value is approximately ±1 percent.

Estimates of the average deviation of CO_2 concentration about the mean values are also indicated in Figure 22. The average deviations in the stratosphere are based upon the observations of Hagemann, Gray Jr., Machta, and Turkevich (ref. 47), The average deviations for the troposphere are based upon a gross interpretation of the values presented in previous sections of this report. Above a height of one km, the average deviation of CO_2 concentration is less than ±3 percent.

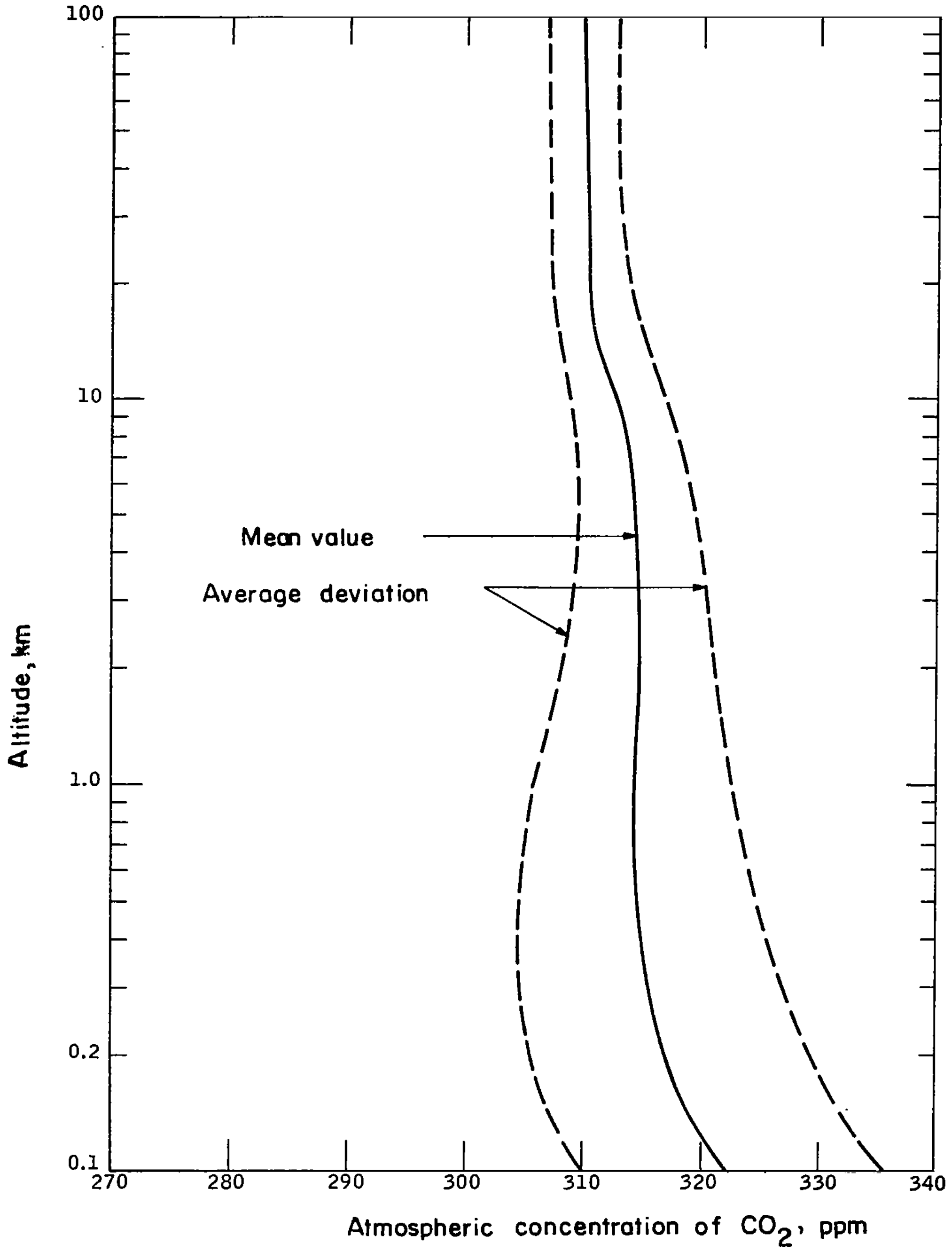

Figure 22. Estimated Mean CO2 Concentration and Average Devialion Concentration as a Function of Height

Between 15 and 30 km, observations of the CO_2 concentration were made from constant altitude balloons, and the results were analyzed by Hagemann, Gray, Jr., Machta and Turkevich(ref. 47). They conclude that the CO_2 concentration is about 312, 310, 313, and 310 ppm for the levels 15.5, 20.0, 24.8, and 28.0 km, respectively. The standard error of a single observation is about from 0.5 to 1.0 percent. The average value for all cases is about 311 ppm with an average deviation of less than one percent and a range of ±2 percent.

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HORIZON RADIANCE COMPUTATION

INTRODUCTION

This section compares the background work of various investigators relative to the computation of horizon radiance in the 15 micron band of carbon dioxide. The problem is to derive theoretical radiance profiles of radiance versus tangent height of the ray or of nadir angle at the sensor. The methods by which the radiative transfer equation is applied to the 15 micron spectral region for different atmospheric conditions will be considered. Finally, the resulting profiles will be compared in terms of data inputs and assumptions.

Infrared radiance emitted by the Earth and atmosphere varies spectrally and with tangent height depending on the absorbing properties of the atmospheric gases and on the temperature and pressure distribution. We are concerned with the infrared radiance in the 15 micron carbon dioxide band that is emitted nearly horizontally, the so-called "horizon radiance". Previous studies of the infrared horizon radiance were based on results of theoretical calculations which utilized atmospheric models to compute the emitted radiance.

THE RADIATIVE TRANSFER EQUATION

Radiant energy emitted by the Earth and atmosphere in the carbon dioxide band can be expressed by the following integral equation called the radiation transfer equation:

$$I(h) = -\int_{\nu_1}^{\nu_2}\int_{1}^{\tau_{\nu o}} J_\nu(T)\, d\tau_\nu\, d\nu + \int_{\nu_1}^{\nu_2} J_{\nu o}(T_o)\,\tau_{\nu o}\, d\nu \qquad (5)$$

where $I(h)$ is the radiance for a given tangent height h, ν is the wavenumber, ν_1 and ν_2 are the spectral limits of interest, $J_\nu(T)$ is the spectral source function at temperature T, τ_ν is the spectral transmittance for carbon dioxide, and the subscript o is the Earth's surface or the surface of an opaque cloud.

The equation lends itself to an immediate interpretation. The double integral is the radiant energy emitted by the atmosphere, and the single integral is the radiant energy emitted by the Earth's surface that is ultimately transmitted to the top of the atmosphere.

PATH OF INTEGRATION

In Figure 23, the integration is carried out as a line integral along an optical path, s. The radiative transfer equation, as stated above, corresponds to the optical path, s, that passes through the atmosphere and ultimately terminates at the Earth's surface. That is, the tangent height is negative or zero. For positive tangent heights, the optical path passes completely through the atmosphere, from outside to interior to outside. In this case, only the atmospheric emission integral in the radiative transfer equation applies to the problem, and the surface emission term is zero.

Sensor Altitude

The altitude of the sensor, presumed to be on a satellite above the atmosphere, determines the relationship between tangent height and nadir angle of view at the sensor. Both quantities have been used as independent variables to define horizon radiance profiles. For parallel radiation to the sensor (see Reference 49 for details), the tangent height is used exclusively as the independent variable. The height of the sensing satellite was chosen at 160 km (ref. 49), 300 km (ref. 50), 370 km (ref. 51), and over the range, 75 km to 40 000 km (ref. 52). These height differences have very little effect on the radiance profile as a function of tangent height in general, and no effect if the atmosphere is horizontally homogeneous.

Refraction

Refraction causes the optical path to curve (Figure 23). True tangent height is the lowest altitude of the actual ray. Apparent tangent height is defined as the altitude of the lowest point of a straight ray reaching the sensor at the same nadir angle as the actual curved ray. In the derivation of the optical path, refraction was considered by a number of previous investigators (refs. 52 through 55). Maximum refraction is about one degree for a ray passing through the atmosphere twice at a tangent height of zero (refs. 53 and 54). It was noted that, since refraction decreases with increasing tangent height, refraction steepens the radiance profile expressed in terms of apparent nadir angle because of the smaller nadir angle change per unit tangent height change. Wark, Alishouse, and Yamamoto (ref. 55) found that the refraction effect is not as large as effects arising from differences in the assumptions of gas transmissivities or differences in techniques of calculation. Since the 15 micron radiance profile is steepest at large tangent heights, the refraction effect is insignificant there. Refraction was ignored in some previous works (refs. 50, 56, and 57). A justification for this by Hanel, Bandeen, and Conrath (ref. 56) was that refraction has no effect on horizon sensing because of the circular symmetry of its angular lifting of the apparent horizon.

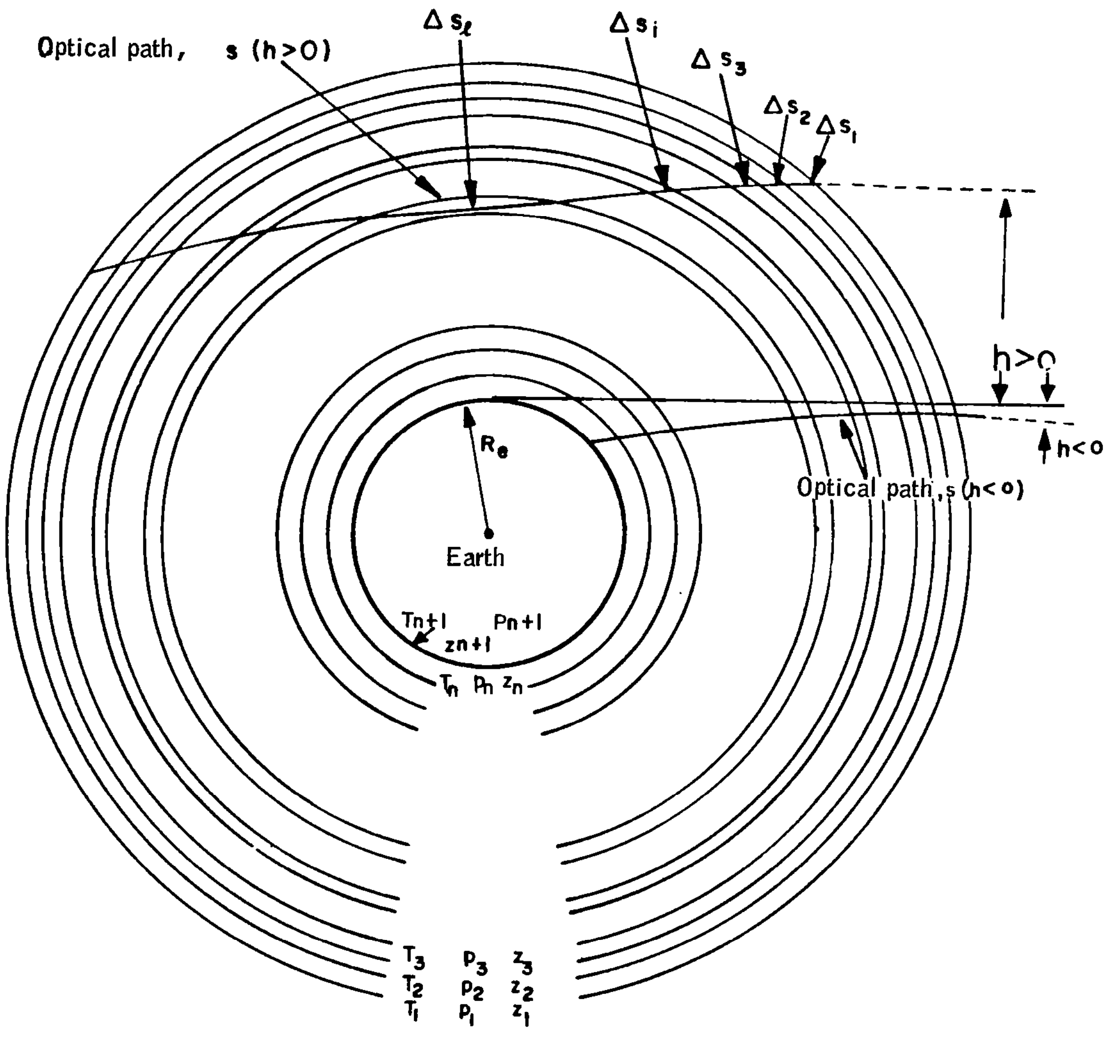


Figure 23. Schematic Diagram of Atmospheric Model for the Computation of the Radiance Profile I (L)

To account for refraction, Wark, et al., (ref. 55) used the refractive index as a function of elevation and assumed that its spectral dependence was small enough to be ignored. The index increases linearly with the air density. To obtain density versus height, McArthur (ref. 58) used profiles of model atmospheres by Cole, Kantor, and Court (ref. 59). Reference used a formula for density as an exponential function of height derived from the hydrostatic equation and the equation of state for ideal gases, an approximation for air. Some investigators, such as Duncan, et al., (ref. 53), computed the density as a function of height by applying the equation of state to temperature and pressure values from profiles of these variables in terms of height. These profiles were from the same model atmospheres used by Oppel and Pearson (ref. 54), the pressure profile being expressed by an exponential function of height.

EMISSION (SOURCE FUNCTION)

In the radiative transfer equation, $J_\nu(T)$ is the radiant energy of emittance per unit wave number. Its value depends on whether the carbon dioxide molecules undergo sufficient collisions to maintain local thermodynamic equilibrium or whether the molecules are excited purely by radiative absorption.

Local Thermodynamic Equilibrium (Blackbody Emission)

This equilibrium is assumed to be valid in most studies. Assuming this, emission is represented by the Planck function, expressing radiance of a black body in terms of wavelength and temperature (refs. 50, 52, 53, 56, 58, and 60).

Emission of the atmosphere, expressed in the first term of the radiative transfer equation, is a particularly sensitive function of temperature. Temperature affects the horizon radiance profile more through the emission than through the curvature of the refracted path or the spectral line widths in the transmission. Simple assumptions were made of just one atmospheric temperature (ref. 51) and two temperatures (ref. 52). Observed temperature soundings were used by Kondratiev and Yakushevskaya (ref. 50); the latter obtained their data from London (ref. 61) and Murgatroyd (ref. 62). Most of the investigators (refs. 53 through 56, 60 and 63), used model atmospheres. Burn (ref. 64) noted that, with the exception of the ARDC Model Atmosphere, different investigators used different temperature profiles even though the corresponding model atmospheres were similar. Wark, et al., assumed for their models that temperature varied with height only in a horizontally homogeneous atmosphere.

Emission at the surface of the Earth or an opaque cloud surface contribute to the radiance at the satellite (given by the second term in the radiative transfer equation) only where the ray intercepts that surface. As noted by Woestman (ref. 51), there is such a contribution only if, in addition, the atmospheric transmissivity has not decreased to zero where the path reaches the opaque surface. In practice, near 15 microns (Hanel, et al., (ref. 56) zero transmissivity is reached along the ray at an altitude above the opaque surface. Consequently, the second term of the radiative transfer equation is always counted as zero for the 15 micron spectral region, even though the term is included in an analyses computer program (ref. 49). Thus, temperature contrasts between the air and the Earth's surface have little or no effect on the horizon radiance profiles. Kondratiev and Yakushevskaya (ref. 60) tried models with contrasts of ±5, ±10, and ±150 degrees and Woestman (ref. 45) hypothesized (ref. 60) a contrast of 71° C.

Absence of Local Thermodynamic Non Equilibrium

Absence of local thermodynamic equilibrium was considered in the calculations (ref. 49) based on those of Curtis and Goody (ref. 65), and Young (ref. 66). This assumption is necessary (ref. 49) to compute the infrared horizon radiance for tenuous regions of the atmosphere above 60 km. Thermodynamic equilibrium prevails in the atmosphere where vibrational (and rotational) energy levels of the gas molecule remain populated according to a Boltzmann distribution determined by the local kimetic temperature. This is possible only if the collisions are frequent enough to maintain such a distribution regardless of the radiative processes. The time required to establish a Boltzmann distribution by collisions is called the relaxation time and is inversely proportional to atmospheric pressure. If the relaxation time is long - as in the upper atmosphere, where collisions are infrequent because of low pressures - a Boltzmann distribution cannot be maintained. Under these conditions, when a photon is absorbed by a molecule, it will be re-emitted (scattered) without passing into the kinetic energy of translation, and a state of absence of local thermodynamic equilibrium prevails. At these levels, the source function must be calculated from considerations of molecular collisions and radiative transitions.

Curtis and Goody (ref. 65) showed that the appropriate source function for the combined effect of collisional and radiative excitation has the form,

$$J_\nu = \frac{\theta}{\theta+\lambda} B_\nu + \frac{\lambda}{\theta+\lambda} F_\nu, \tag{6}$$

where

$$F_\nu = \frac{\int d\epsilon \int d\nu \; nK_\nu I_\nu}{4\pi \int d\nu \; nK_\nu} \tag{7}$$

and $\theta = 0.41$ seconds, the radiative lifetime of the 15 micron vibration band of CO_2; λ, the vibrational relaxation time, is Z^*/Z; Z^* is between 10^3 and 10^6, the required number of collisions; Z is the number of collisions per second; F_ν is the source function for incoherent scattering; I_ν is the external radiance incident on the source point; n is the CO_2 number density at that altitude; K_ν is the absorption coefficient per molecule; and $d\epsilon$ is a small incremental solid angle.

There is uncertainty about the exact dependence of J_ν, which depends on the uncertain measurements of Z^* and the difficult and uncertain calculations of F_ν.

TRANSMISSIVITY MODELS AND SOURCES OF DATA (15 MICRON REGION)

Carbon Dioxide

The other key parameter besides the source function in determining the radiance profile is the absorptivity (or transmissivity) as a function of an optical path variable (u) and of the spectral absorption coefficient $k(\nu, T)$, a function of the molecule. In practice, a spectral band of finite spectral width ($\Delta\nu$) is considered with an averaged $\bar{k}_{\Delta\nu}(T)$, depending on the particular band under consideration.

In general, for turbid atmospheres at low altitudes, and in an atmospheric window at shorter wavelengths than 10 microns, there might be an important contribution to the transmissivity due to acattering of radiation by molecules (Rayleigh) and aerosols (Mie). But at 14-16 microns, where the atmosphere is nearly opaque for a path from infinity to 10 km, due to the intense CO_2 absorptivity, the scattering component is negligible compared to the absorptivity (ref. 67). Most authors treat the 14-16 micron region as if the only absorbing species were carbon dioxide; we shall, therefore, concentrate on the treatment of CO_2 transmissivities, reserving a discussion of the treatment of O_3 and H_2O to a later section.

For a homogeneous path, the absorption A, or the transmission, $\tau = 1-A$, is a function of the pressure P, the temperature T, and optical cross section (or "path") $U = ns$, where n is the molecular number density of the absorbing species, and s the physical path length. The practical unit of U, atm-cm, is obtained by dividing the rational unit, molecules/cm^2, by Loschmidt's number, $L_o = 2.687 \times 10^{19}$ molecules/cc of gas at Standard Temperature and Pressure (STP). By use of the Gas Law, $n = mP/kT$, where k is the Boltzmann constant and m is the CO_2 mixing ratio, the absorption is reduced to a function of three path variables, (P, T, U) besides $\bar{k}_{\Delta\nu}(T)$.

For an inhomogeneous path, it has become customary to define an "effective homogeneous" U_e, P_e, T_e as integrals over the entire path:

$$U_e = \int n\,ds \quad \text{or} \quad (dU_e = n\,ds) \tag{8}$$

$$P_e = U_e^{-1} \int P\,dU_e \tag{9}$$

$$T_e = U_e^{-1} \int T\,dU_e \tag{10}$$

Spectral line strengths and absorption coefficients for CO_2. -- The intense band of spectral absorption in air in the 14-16 micron region is predominantly due to the fundamental bending vibration-rotations of the linear (O-C-O) molecule. Molecular mechanics and line strengths (or intensities), and positions within this band, are treated in some detail in the works of previous investigators (refs. 64 and 68 through 72). Table 9 lists the relative abundances of the eight isotopes of CO_2 and the relative intensities of the 15 strongest vibrations which each isotope undergoes. Listings of individual line strengths in order of wavenumber are also given by the above references. Figure 24 is an illustration of the distribution of these line strengths ($S = \int k d\nu$) within the spectral region. Each vibration contains a P, Q, and R branch corresponding to the rotational transitions $\Delta J = 1, 0,$ and -1. For the principal vibrational transition (01^10-00^00) only, the temperature dependence of line strength is illustrated, which will later be of interest. Thus the entire region contains about 5000 lines, including those more than 10^{-5} of the largest intensity, which may be classified into three rotational branches in 15 vibrations, in eight isotopes.

The spectral absorption coefficient resulting from each line is broadened by a combination of Doppler and collisional (Lorentz) broadening. Since the total Doppler width (between half maxima) is about 0.0011 cm^{-1} at 300° K, a high resolution treatment of the spectral absorption coefficient would require integration over more than 100 000 spectral intervals to cover the band range of 600 to 725 cm^{-1}. For computational convenience, some form of low resolution treatment, resulting from theoretical band models or experimental data at low resolution, is required, and this approach is taken by all investigators.

The effect of pressure on the transmissivity. -- In general the transmissivity or the absorptivity is a function of (ν, U, P, T). Computational convenience and speed dictate that the reduction of the number of variables be from four to two or one. The pressure effect shall be discussed first. It has already been seen that U is proportional to the molecular density of CO_2, which is proportional to P/T, by use of the Gas Law. A further pressure effect ensues as a result of collision broadening of the line shape. The well-known Lorentz formula for the absorption coefficient contribution from a single line "i" is

$$K_i(\nu) = \frac{S_i \alpha_i}{\pi} \left[(\nu - \nu_i)^2 + \alpha_i^2 \right]^{-1} \tag{11}$$

where S_i is the strength of the line, and α_i is the half-width at half-maximum. Further, the half-width is proportional to the collision rate, which is proportional to the pressure divided by square root temperature.

TABLE 9. - ISOTOPE CONCENTRATIONS AND BAND INTENSITIES ON THE 15 MICRON CARBON DIOXIDE BAND

Isotope C	Isotope O	Isotope O	Relative abundance	Percent
12	16	16	1.00	98.4
13	16	18	1.12×10^{-2}	1.10
12	16	18	4.0×10^{-3}	0.4
12	16	17	8.0×10^{-4}	0.08
13	16	18	4.5×10^{-5}	4.4×10^{-3}
13	16	17	8.9×10^{-6}	8.7×10^{-4}
12	18	18	4.1×10^{-6}	4.0×10^{-4}
12	17	18	1.6×10^{-6}	1.5×10^{-4}

[From Sasamori (1959)]

Lower level $V_1'' V_2''^{\ell''} V_3''$	Upper level $V_1'' V_2''^{\ell''} V_3''$	Band center cm^{-1}	$C^{12}O^{16}$ band intensities, $cm^{-2}\ atm^{-1}$ 300°K	265°K	240°K	218°K
$0\ 0^0\ 0$	$0\ 1^1\ 0$	667.40	212	221.8	227.5	231.8
$0\ 1^1\ 0$	$0\ 2^0\ 0$	618.03	4.7	3.21	2.27	1.55
$0\ 1^1\ 0$	$1\ 0^0\ 0$	720.83	6.2	4.19	2.97	2.02
$0\ 1^1\ 0$	$0\ 2^2\ 0$	667.76	16.6	11.3	7.97	5.43
$0\ 2^0\ 0$	$0\ 3^1\ 0$	647.02	1.13	0.51	0.261	0.122
$0\ 2^0\ 0$	$1\ 1^1\ 0$	791.48	0.022	0.010	0.0051	0.0024
$0\ 2^2\ 0$	$0\ 3^1\ 0$	597.29	0.157	0.071	0.34	0.0155
$0\ 2^2\ 0$	$1\ 1^1\ 0$	741.75	0.14	0.063	0.030	0.0136
$0\ 2^2\ 0$	$0\ 3^3\ 0$	668.3	0.85	0.38	0.18	0.083
$1\ 0^0\ 0$	$0\ 3^1\ 0$	544.26	0.0044	0.0019	0.00091	0.00040
$0\ 3^3\ 0$	$0\ 4^2\ 0$	581.2	0.0042	0.0012	0.00041	0.00013
$0\ 3^3\ 0$	$1\ 2^2\ 0$	756.75	0.0059	0.0017	0.00057	0.00017
$0\ 3^1\ 0$	$1\ 2^2\ 0$	828.18	0.00049	0.00015	0.000051	0.000016
$0\ 3^1\ 0$	$1\ 2^0\ 0$	740.5	0.014	0.0043	0.0015	0.00046
$0\ 4^4\ 0$	$1\ 3^3\ 0$	769.5	0.0004	0.00008	0.000016	0.0000024
Total intensity			241.8	241.5	241.2	241.0
Qv			1.0886	1.0562	1.0379	1.0250

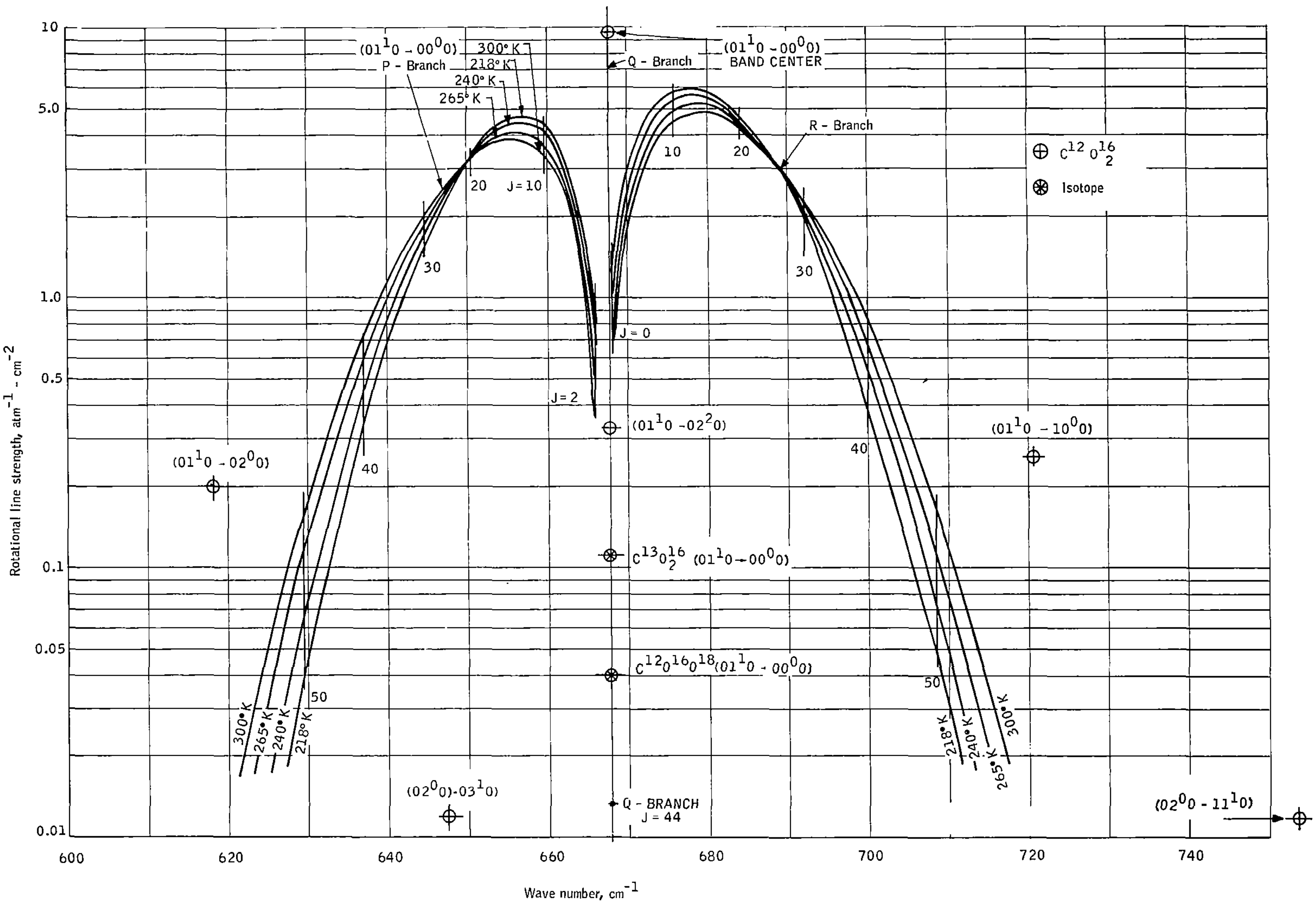


Figure 24. Plot of Rotational Line Strengths, CO_2, from Yamamota Sasomori, 1960

$$\alpha = \alpha_o \frac{P}{P_o}\sqrt{\frac{T_o}{T}} \qquad (12)$$

where α_o is the half-width at some standard pressure and temperature, P_o, T_o. Usually all the lines in a band have about the same half-width.

The most generally accepted experimental value for the reference line half-width in the 15 micron, CO_2 band is that determined by Kaplan-Eggers (ref. 27), α_o = 0.064 cm at P_o = 1 atm, T_o = 298°K.

If the dominant lines contributing to the absorption are sufficiently strong that the absorption coefficient at line peak ($S_i/\pi d$) is much greater than U^{-1}, then it can be shown that the average effective absorption coefficient $\bar{k}(\Delta\nu, T)$ over a spectral interval $\Delta\nu$ containing a number of strong lines is proportional to (αU), thus to ($UP/\sqrt{T}$), or to $P^2/T^{3/2}$). This τ (UP) rule was first stated by Elsasser (ref. 75), and the theoretical justification was discussed in more detail by Plass (ref. 76).

The pressure effect and the τ(UP) rule are illustrated in Figure 25 by the transmissivity data for 300°K averaged over 675-700 cm^{-1} assembled by Wark and Alishouse (privately communicated) from the work of Yamamoto and Sasamori (ref. 68). For U/P >> 1 cm, the transmissivity tends in the limit to a function of the single variable, UP. In this region the absorptivity at the line peaks is saturated (totally absorbing). In the opposite limit, U/P >> 1 cm, the transmissivity is a function of U alone, independent of P. Here the lines are greatly pressure broadened and overlapping, and the peaks are unsaturated.

Figure 25 also shows the range of (U, P) values covered by optical paths which orginate totally outside the atmosphere and then pass through some part of the atmosphere for different paths ranging from vertical paths to horizontal paths at various tangent heights. These paths lie wholly within the range of validity of τ(UP), with U/P = 10^3 to 10^4 cm. Therefore, for this class of path, the transmissivity may be treated as a one-dimensional function of UP, with considerable saving in computational effort. This rule can be shown to be the theoretical justification for the use of Equation (9) for the pressure weighting is an inhomogenous path.

<u>The effect of temperature on the transmissivity</u>. -- Temperature effect has been treated in detail by Sasamori (ref. 70). It has been shown that the effect of Lorentz broadening can be compensated by adjusting the optical path variable to an "effective"

$$U^* = U\left(\frac{P}{P_o}\right)\left(\frac{T}{T_o}\right)^{-1/2} \qquad (13)$$

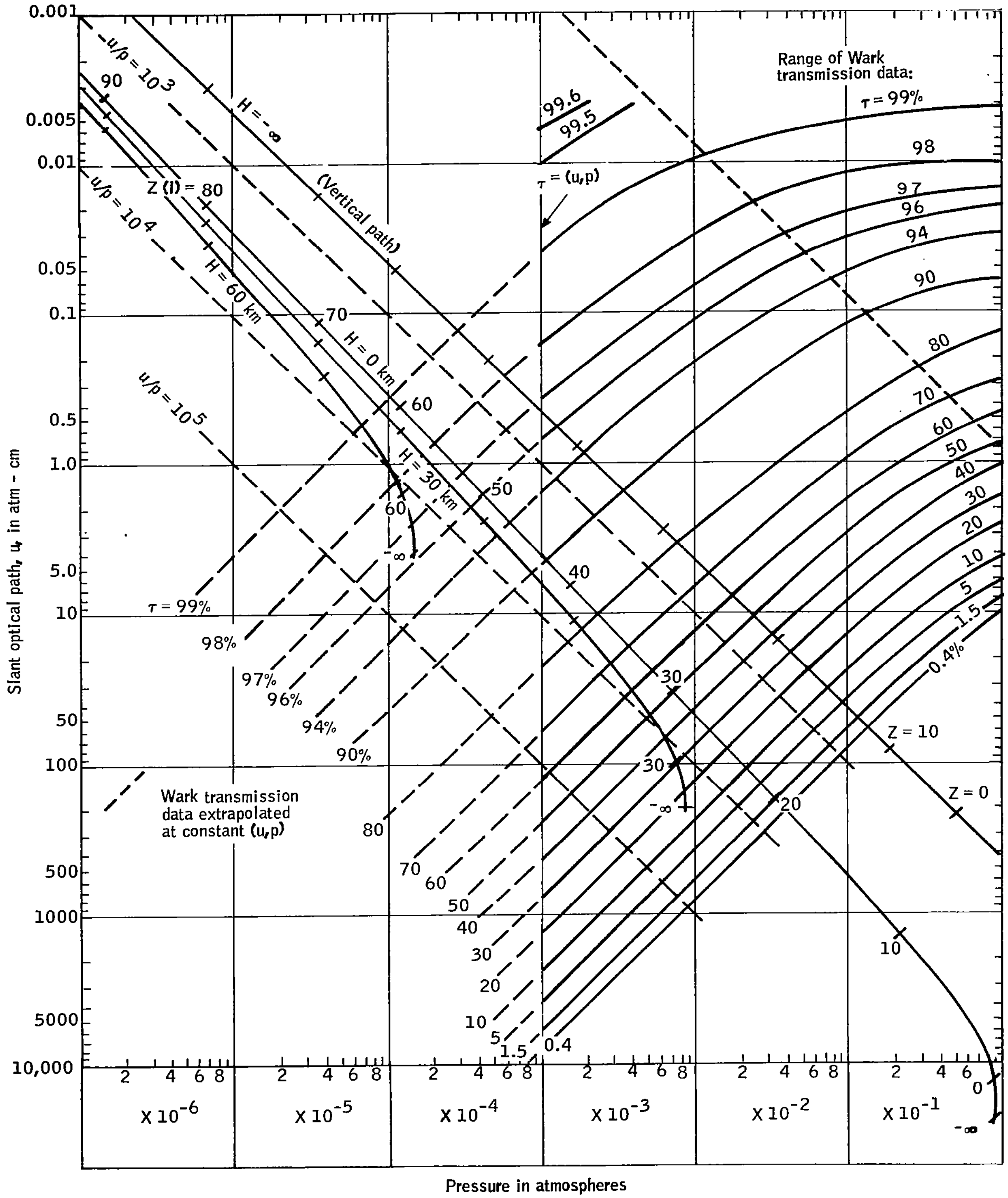


Figure 25. Lines of Constant Transmission in the U, P Plane, Approximate Focus of U, P Values for Tangent Optical Paths, H, From Outside the Atmosphere to Shell = (I)

In addition, the temperature affects the absorption coefficient of the molecule ($\bar{k}$), which in all models is proportional to the effective line strengths in the spectral region. This is illustrated in Figure 24 and Table 9.

The effect of temperature on the line strength for an equilibrium system depends on the variation of the Boltzmann distribution of molecules in energy levels involved in the line transition. Theoretically the line strength can be written as

$$S(T) \propto (N_u - N_1)\, A_{ul} = NQ^{-1}\left(e^{-\frac{E_u}{kT}} - e^{-\frac{E_1}{KT}}\right) A_{ul} \qquad (14)$$

where u, 1 are the upper, lower states of the transition, A_{ul} is the transition probability, which is independent of temperature, N is the molecular density, E is the energy of the level, k is Boltzmann's constant, and Q(T) is the partition function.

Thus, the temperature effect varies the absorption coefficient in a nonlinear fashion and is somewhat difficult to treat with general rigor. Figure 24 shows that even the sign of the effect can vary with wave number. As a practical matter, atmospheric temperatures range from about 200 to 300°K, and Sasamori and others have found that it is adequate to treat this temperature effect by a linear variation about a normalized mean temperature, say T_o = 250°K,

$$\bar{k}(\nu, T) = \bar{k}(\nu, T_u)(T/T_o)^{\gamma_2(\nu)} \qquad (15)$$

or

$$\bar{k}(\nu, T) = \bar{k}(\nu, T_o)[1+\gamma_2(\nu)\ (T-T_o/T_o + \dots)] \qquad (16)$$

where

$$\gamma_2 = \frac{T_o}{S(T_o)} \left[\frac{dS}{dT}\right]_{T_o} \qquad (17)$$

Thus, in summary, by combining Equations (13) and (15), the transmissivity or the absorptivity for narrow spectral intervals in the 14-16 micron spectral region due to carbon dioxide in the 200-300°K temperature region for any pressure, if U >> P, can be written as a function of the single variable

$$k^* U^* = \bar{k}_o\, U\, P^{\beta}\, (T/T_o)^{\gamma_1 + \gamma_2} \qquad (18)$$

Theory indicates that $\beta = 1$ and $\gamma_1 = -1/2$, and both are independent of wavenumber. However, for generality, these are left to be determined by optimum curve fitting techniques from experimental or theoretical transmissivity data. The undetermined "constants", $\bar{k}_o$ and γ_2, are expected theoretically to vary significantly with wavenumber.

Sources of transmissivity data for carbon dioxide (14-16 microns). -- It has now been demonstrated that transmissivity should be approximately represented by a universal function of a single variable. It remains to determine the shape of this function and to test these conclusions with transmissivity data for carbon dioxide in the 14-16 micron spectral region. Data may be obtained from experimental measurements at resolutions of the order of 5 to 10 cm^{-1}, or they may be computed by means of theoretical absorption models and the use of spectroscopic constants, which are usually themselves reduced from the experimental spectroscopic data.

The most generally accepted source for experimental data covering a wide range of the independent variables U, P is from the work done at Ohio State University by Howard, Burch, Williams, Gryvnak, Singleton, and France (refs. 77 and 78). Many spectral transmissivity curves in the ranges P = 0.002 to four atm and U = 0.002 to 3000 atm-cm are published. Most of the data are taken at ambient laboratory temperatures with a few additional runs at temperatures up to 65° C.

The exact shape of the function $A(k^*U^*)$ depends on the arrangement of line positions and intensities within the interval. A number of theoretical band models have been developed for a variety of arrangements. The Elsasser regular band model would appear to be most nearly similar to the actual arrangement in the carbon dioxide bands (see Figure 24). The Elsasser model assumes a set of lines of uniform intensity (S) and uniform spectral spacing (δ). Then, the absorption in the strong line region ($SU >> \pi\alpha$) is given by

$$A = \text{erf} \left(\frac{2\pi SU\alpha}{\delta^2}\right)^{1/2} \tag{19}$$

Thus in terms of the Equation(18)

$$\bar{k}_o = \left[\frac{2\pi S\alpha}{\delta^2}\right]; \quad \beta = 1, \quad \gamma_1 = -1/2$$

and γ_2 may be determined from Equation(17) from data on line strength versus temperature which was published by Yamamoto and Sasamori and Young (ref. 66).

Yamamoto and Sasamori (refs. 68 and 69) used the Elsasser theory to compute the transmissivity of carbon dioxide from 550 to 830 wave numbers, from U = 10^{-3} to 10^4 atm-cm, P = 10^{-3} to 1 atm, and at T = 218, 240, 265, and 300°K. They used a model due to Kaplan (ref. 79) sometimes called the Random Elsasser Model, to combine the effects of several individual Elsasser bands in a single spectral region.

Stull, Wyatt and Plass (refs. 71 and 72), and Drayson (ref. 80), have used the Quasi-Random Model of Wyatt, Stull and Plass (ref. 81) to compute and publish extensive tables of transmissivity data over ranges of U, P, T similar to those of Yamamoto and Sasamori. This model is too involved to discuss here, and the reader is referred to the above references. In addition, Plass (ref. 82) has extended these calculations to slant paths in the atmosphere; some cases extend as high as 50 km. This is apparently the only source of data for effective pressures as low as 3.7×10^{-4} atm., except by extrapolation from higher pressures (e.g., by the method illustrated in Figure 25).

These sources of extensive data are in reasonable agreement with each other, considering the different methods by which they were obtained.

Carpenter, House, and Mariano (ref. 49) have subjected both the homogeneous and slant path data of Plass (ref. 82) to an empirical curve fitting computation to accurately determine the best mean square coefficients in the following form:

$$\begin{aligned} \ln(-\ln \tau) = {} & C_o + C_1 x + A_1 \Delta T + C_2 x^2 \\ & + B_1 x \Delta T + A_2 \Delta T^2 + C_3 x^3 \\ & + B_2 x \Delta T^2 \end{aligned} \tag{20}$$

where

$$x = \log_e (UP)$$

$$\Delta T = T - 250°K$$

$$\Delta T^2 = T^2 - (250)^2.$$

Values of the derived coefficients are shown in Table 2 for 10 different spectral intervals. The quadratic and cubic terms are not exactly consistent with Equation (18), but these coefficients are very small and can be neglected. C_1 is found to be nearly 1/2 in all 10 spectral intervals. By comparing Equations (19) and (20) in the region $x << 1$, it can be shown that $k_o \gamma$ can be derived from C_o, A_1 as follows:

$$k_o(\nu) = \frac{\pi}{4} e^{2 C_o} \tag{21}$$

$$\gamma(\nu) = \gamma_2 - \frac{1}{2} = 250\ A_1 \tag{22}$$

These are also listed in Table 10, and it is seen that they do vary significantly with wave number. k_o is the value of the effective absorption coefficient k^* at 250° C. γ_2 is consistent with the averaged thermal derivative of the line strength, as noted by comparing Equation (17) with Figure 24. Equation (18) matched to the Plass points at $k^* u^* << 1$ does not fit as well as the empirical form.

$$\ln(-\ln \tau) = 0.076 + 1/2 \log_e (k^* U^*) \tag{23}$$

which gives a reasonable approximation to the data for all ν, U, P, T, if used with the values of k_o, γ listed in Table 10.

The effect of Doppler broadening. -- Doppler broadening of spectrum lines results from the Doppler shift in absorption frequencies due to the thermal velocity of the molecules; thus, the Doppler line width is proportional to the square root of temperature, but is independent of pressure. At about 33 km, or at a pressure of about 0.07 atm, the Doppler half width ($\Delta\nu_1$) equals the Lorentz half width ($\Delta\nu_1$) for the 15 micron CO_2 band. At higher altitudes the absorption line spectral profile has a mixed Doppler-Lorentz line shape and a half width of about $\Delta\nu_p = 0.00056\ cm^{-1}$.

Plass and Fivel (ref. 84) and others have pointed out that this has the effect of producing a positive inflection on the experimental absorption curve of growth. There are no experimental data on the required low pressure and extremely long optical paths.

The data discussed in previous sections cover this range of U, P only by theoretical extrapolation, based on a pure Lorentz line shape. Unfortunately, the Doppler correction destroys the one-dimensional (UP) simplicity of the previous treatment.

Carpenter, House, and Mariano (ref. 49) have developed an approximate method for providing a Doppler correction to a transmission estimate from pure Lorentz data. The corrected transmission is written

$$\tau_{cor} = \bar{\tau}_L \left[1 - \frac{1}{\Delta\nu} \sum_{S_1}^{S_3} \Delta W(S) \right] \tag{24}$$

TABLE 10. - CURVE FIT COEFFICIENTS

$\Delta\nu$	C_o	C_1	A_1	$\ln k_o = 2C_o - 2 \ln 1.13$	k_o	$\gamma = 250\ A_1 \times 2$
600-615	-1.998	0.5297	0.02655			
615-625	-0.8065	0.4779	0.02441			
625-635	-0.8933	0.5207	0.01855	-2.0310	0.131	
635-645	-0.2468	0.5174	0.009212			
645-665	+0.4692	0.5324	-0.00037			
665-670	+1.581	0.4545	-0.00185	+2.9176	18.50	
670-690	+0.3094	0.5323	+0.00026	+0.3744	1.454	0.13
690-705	-0.5223	0.5263	0.01534			
705-715	-1.361	0.5327	0.02642			
715-725	-0.8322	0.4667	0.02220			

where $\bar{\tau}_L$ is the extrapolation from Lorentz data and ΔW is the difference in "equivalent width (Ref. 85) for a single line of Lorentz or mixed shape. Beyond the strength limits $S_1 = 4\,\Delta\nu_L/U$ and $S_3 = \Delta\nu_D^{\,2}/U\Delta\nu_L$, this difference vanishes. This difference was calculated as a function of (ν, U, T) for the case $P = 10^4 U$, which corresponds to points on horizon rays (see Figure 25). The sum was executed over the line strength data listed by Stull, Wyatt, and Plass (ref. 71). The results show that the Doppler correction adds about one or two percent to the absorptivity between about 45 and 65 km.

Ozone and water vapor effects. -- The strong ν_2 fundamental vibration of CO_2 is the dominant atmospheric absorber and emitter in the 14-16 micron region. There are, however, weak absorptions due to the wing of the H_2O rotational band and a weak ozone band centered at 710 cm^{-1}. The order of magnitude of these effects is illustrated in Figure 26 by the data of Elsasser and Culbertson (ref. 86), showing the smoothed (or low resolution) "generalized" spectral absorption coefficient (k*) of CO_2, H_2O and O_3.

The net spectral transmission for a mixture of these three gases is obtained from the product of the contribution for each species,

$$\tau = \tau_{CO_2} \cdot \tau_{H_2O} \cdot \tau_{O_3} \quad . \tag{25}$$

Justification for this rule requires only that the statistical line positions between species be randomly correlated.

A discussion of computations of absorptivity and the radiance of horizon paths for a variety of spectral bands in the 600 to 725 cm^{-1} region is given in Reference 49. The results indicate that, for practical purposes, ozone and water vapor effects are negligible when the entire 600 to 725 cm^{-1} region is considered as a single interval.

FORMULATION AND METHOD OF SOLUTION OF RADIATIVE TRANSFER EQUATION

ASSUMPTIONS

Limits of Spectral Intervals

This topic includes the extreme limits of the entire spectral interval of measurement plus the division of this interval into smaller spectral subintervals for the purpose of numerical integration of the radiative transfer equation.

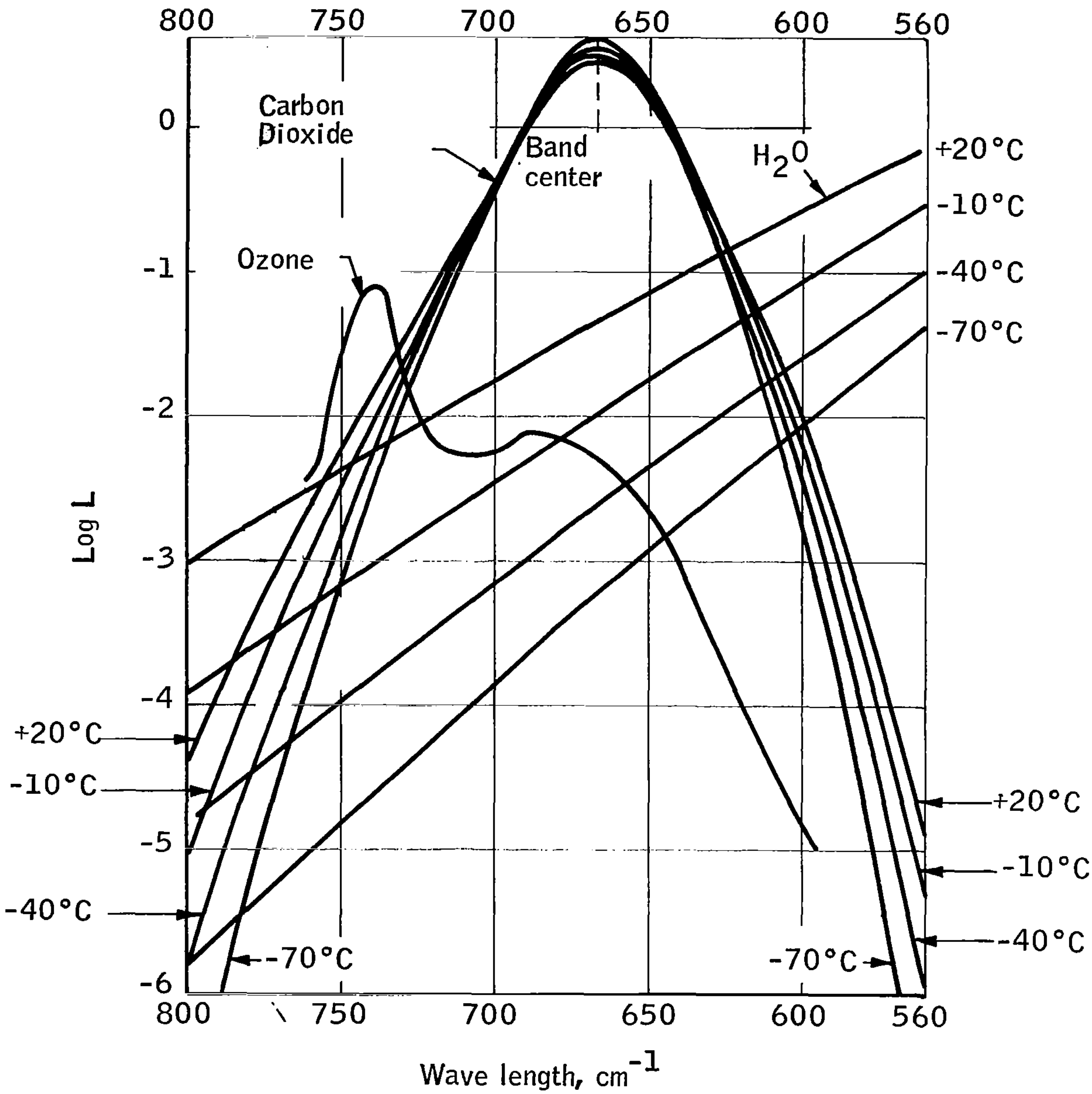


Figure 26. Generalized Absorption Coefficients for 15-Micron Band [From Ref. 86]

Because of the large variability of transmissivity with wavelength, or wave number, the characteristics of the computed horizon radiance profiles are strongly dependent on both the width of the overall spectral interval and its resolution into subintervals.

Some very broad infrared spectral intervals were considered by Duncan, et al., (ref. 53) (5-40 microns), Wexler and Brooks (ref. 52) (8-30 microns), and Wark, et al., (ref. 55) (7.7-16.7 microns), but they do not represent the 15 *micron carbon dioxide absorption band because they include the atmosphere* transmission window near 10 microns. Many investigators (refs. 50, 51, 60, 80, and 83) worked with the narrower range of 12-18 microns, centered at 15 microns. Even though this range does not include the atmospheric window, Kondratiev and Yakushevskaya (ref. 50) found variations of horizon radiance with temperature changes in the troposphere. Earle (ref. 87) found that this variability occurred in the right and left subintervals, 12.30-14.80 microns and 16.0-18.2 microns, of the 12.30-18.20 micron interval, and that the 14.29-16.0 micron radiance profile was much less variable with climatological differences. Similarly, Honeywell (ref. 49) showed less variability in radiance for the total of eight subintervals, encompassing wave numbers 615-715 cm^{-1} (13.99-16.26 microns), than when one subinterval was added at each end to make a total of 10 subintervals, 600-725 cm^{-1} (13.79-16.67 microns).

Their subintervals varied in spectral width from 5 to 15 cm^{-1} (0.1 to 0.4 microns). Most investigators obtained a spectral resolution for their radiance profiles corresponding to subintervals of one micron or less. Duncan, et al., (ref. 53) divided the 5-40 micron range into 110 subintervals; McArthur (ref. 58) had a spectral width of 0.7 microns in the 14.8-15.5 micron interval; Hanel, et al., (ref. 56) had subintervals of 0.5 to 1 micron; and Wark, et al., (ref. 55) used 77 subintervals, most of them 25 cm^{-1} wide. The best resolution was obtained by Drayson (ref. 80), who broke the spectrum into 0.1 cm^{-1} (about 2×10^{-3} microns) subintervals. In the carbon dioxide 15 micron band, he considered very small subintervals of 0.001 cm^{-1} (about 2×10^{-5} microns) to allow for the variation of transmissivity across a spectral line. It is impractical to utilize such fine resolution over the entire 15 micron carbon dioxide band. Honeywell (ref. 49) stated that the number of spectral subintervals of width 0.0006 cm^{-1} required to cover the 600-750 cm^{-1} (13.33-16.67 micron) interval would be 250 000.

Curvature of Earth's Surface and Atmosphere

The geometric curvature of the Earth and any surface of constant height in the atmosphere nearly always exceeds the refractive curvatures of infrared ray paths. Consequently, it is more important to include geometric curvature than refraction effects in horizon radiance calculations. A curved Earth and atmosphere were incorporated in the models of most investigators. However, Drayson (ref. 80) and McArthur (ref. 58) assumed plane parallel stratified atmospheres to fix the direction of the height coordinate in order to simplify the mathematical formulation of slant transmission. Wark, et al., (ref. 55) showed that exact radiance values at the Earth's limb are only about 1 percent more precise than an extrapolation from the smaller zenith angles where the plane parallel approximation is valid.

Division of Atmosphere into Layers

Levels are defined in the atmosphere to allow the integrals in the radiative transfer equation to be changed to finite summations with definite limits. This simplification is done for convenience, since the source function is not written as an analytical function of transmissivity, the variable of integration.

Kondratiev and Yakushevskaya (ref. 50) selected pressure intervals of 100 mb from the 1000 mb level (near sea level) to the 100 mb level (about 16 km) and then chose the 50, 25, 15, 10 and 5 mb levels (about 20, 25, 28, 31, and 36 km, respectively). The corresponding height intervals were about one km for heights below the 600 mb level (about 4 km), and varied from 1-1/2 to about 5 km for greater heights. They found that when they doubled the number of altitude intervals, the resulting radiance values changed by not more than 1-3 percent. The finest spacings were used by Woestman (ref. 51) and Hanel, et al., (ref. 56), who chose height intervals of 0.1 and 0.05 km, respectively.

The number of height intervals used by different investigators varied considerably. Wexler and Brooks (ref. 52), McGee (ref. 63), Duncan, et al., (ref. 53), and Wark, et al., (ref. 55) selected 3, 9, 34, 80, and 200 levels, respectively. Honeywell (ref. 49) concluded that 60-70 levels are sufficient to get good results.

The greatest chosen height varied likewise. Kondratiev and Yakushevskaya (ref. 50) selected their maximum height at the five mb level (about 36 km). Wark, et al., (ref. 55) went up to the 0.1 mb level (about 64 km). Hanel, et al., (ref. 56) and Honeywell (refs. 11 and 49) went even higher, up to 70 and 90 km, respectively.

TECHNIQUE FOR EVALUATION OF RADIANCE

In the radiative transfer equation, the source function is known in terms of atmospheric temperature rather than transmissivity, the variable of integration. Since transmissivity for a spectral interval can be found as a function of temperature on a slant path, it is possible to change the variable of integration to temperature before performing the integration (ref. 55). Whether or not this transformation is made, the radiance results are inexact due to the use of different approximate methods of summation (ref. 64). However, the errors are not as great as would result from the omission of thin or scattered clouds in clear or opaque cloud models (ref. 55).

The radiative transfer equation was integrated numerically by a computer in the methods used by Honeywell (ref. 49) and Wark, et al.,(ref. 55) when transmissivity values were obtained directly from tables. On the other hand, the integration was performed graphically by Burn (ref. 64) and Hanel, et al., (ref. 56). Hanel constructed a radiation chart similar to that of Möller (ref. 88). They found that the radiation chart helped to take into account the Earth's surface, clouds, and the symmetrical part of the atmosphere farther than the minimum tangent-height point from the sensor.

Integration of Radiance from the Emitting Layers

There are several ways of representing the particular portion of the total radiance reaching the sensor from each layer in the atmosphere. As suggested by Honeywell (ref. 49), it can be designated by a fraction of the total radiance, by the amount of radiance that came from that layer, or by the change in transmissivity from one side of the layer to the other. The latter is a weighting factor serving as an approximation, which is good only if the emission itself varies only slightly with emission height (as would be the case in an isothermal atmosphere).

Although radiance is emitted over a wide range of height, all but a negligible amount comes from a layer about 400 mb (7 kilometers) in vertical extent (ref. 60). The emitting layer is entirely in the atmosphere, the major part being at high levels (ref. 50).

Repetition of Integration for Different Tangent Heights

Horizon radiance is related to the tangent height of the ray in such a complicated manner that it is impractical to express the radiance theoretically as a continuous analytical function of tangent height. Therefore, it is customary to compute horizon radiance separately by repeating the integration of the radiative transfer equation for each of specified individual values of tangent height. The resolution of the horizon radiance profile increases with a decrease in the selected tangent height intervals, or their vertical spacings.

Wark, et al.,(ref. 55) chose 15 values of tangent height to supply 15 values of radiance for each horizon profile they computed. The tangent height resolution provided by Honeywell (refs. 11 and 49) called for a five km spacing of tangent height between -30 and -10 km, two km between -10 and 0 km, one km between 0 and 50 km, two km between 50 and 60 km, and a five km spacing between tangent heights of 60 and 80 km.

After this consideration of assumptions and methods, the resulting theoretical radiance profiles, which will form the subject of the rest of this report, may be examined.

RESULTING THEORETICAL RADIANCE PROFILES

CHARACTERISTICS

Limb Effects

Lambert's law prescribes that the intensity of radiance received from a layer of uniform composition and temperature is independent of the direction from which it is viewed. If the Earth's atmosphere were homogeneous in these respects, a sensor in space would note the same amount of radiance coming from the atmosphere's limb as from lower levels, i. e., there would be no limb effects. Actually, a decrease of atmospheric temperature with increasing in height contributes to limb darkening, which means decreasing radiance for the entire profile, due to the smaller emission at lower temperatures. Limb brightening, for which the radiance reaches a maximum at a given tangent height and then decreases at greater heights, may be expected under some conditions, such as when there is an inversion of temperature (ref. 49) or an increase in the emitting constituent with increase in height.

Most computations of limb effects for the 15 micron spectral region revealed limb brightening. Both Wark, et al., (ref. 55) and Hanel, et al., (ref. 56) found limb brightening for all four atmospheric models which they used. Hanel, et al., found that radiance was quite uniform, but exhibited a maximum near a tangent height of 20 km. McArthur (ref. 58) found limb brightening that was definite in summer and small in winter. Both temperate and tropical atmospheres had small brightening according to Burn (ref. 64). The only limb brightening found by Kondratiev and Yakushevskaya (ref. 50) was for a high altitude when there was a very high cloud cover. Limb darkening resulted from their calculations for all situations in which either the latitude or cloud height was low, clear sky being defined as a cloud at zero height.

Slope of Radiance Profile

The plot of radiance versus tangent height, known as the horizon radiance profile, has a positive slope only below the level of maximum radiance, which is characteristic only of cases of limb brightening. At higher tangent heights, the profile slope is always negative as the radiance approaches zero at the greatest heights. The negative slope is almost constant, indicating a linear decrease of radiance, to 55 km according to McArthur (ref. 58); Kondratiev and Yakushevskaya (ref. 50), however, found that the radiance was more closely proportional to an exponential function of height, since the profile on semi-logarithmic paper was almost a straight line. Honeywell (ref. 49) found that, if the radiances were expressed as fractions of their peak values, the resulting profiles were quite similar to each other. Wark, et al., (ref. 55) found the most consistent steep profiles at high levels to be in the 650-576 cm^{-1} (14.8-15.4 micron) spectral subinterval. The greatest negative steepness is reached at tangent heights of about 10 km (ref. 50); then the profile flattens out at greater heights. The region of maximum steepness has been described as a discontinuity by Hanel, et al., (ref. 56) and as the general boundary of earth-sky interface by Woestman (ref. 51). In this sense, this portion of the radiance profile assumes the characteristics of a horizon, which will now be discussed.

The optical limb, or horizon, can be defined in a general way as a level where some phenomenon associated with the planet appears (ref. 53). This leaves room for many different definitions. For example, a standard horizon has been defined by Wexler and Brooks (ref. 52) as the height of the -40°C isotherm of the standard atmosphere. It is more useful to define the horizon such that its time variations can be included. The horizon is often defined in terms of the slope of the radiance profile. The inflection point of the radiance profile, where the negative slope is a maximum, was used by Wexler and Brooks (ref. 52) to define the horizon. Its height varies about one kilometer for every 10°C change in stratospheric mean temperature, averaged between 18 and 38 km (ref. 49). An alternative definition places the horizon at the tangent height where the radiant intensity was 80 percent of the maximum intensity. A more sophisticated definition by Duncan, et al., (ref. 53) states that the horizon is the tangent height with the maximum difference between the radiances of two separate spectral subintervals of the carbon dioxide band.

Maximum Tangent Height of Radiance

Maximum tangent height of radiance can be defined as the tangent height which the profile curve drops to a radiance so small as to be indistinguishable from zero on the graph. This maximum height varies considerably between the results of different investigators. The maximum height is in the neighborhood of 60 km (ref. 49) and is lower for a cold air column than for a warm one. Values of 42, 65, 71, and 76 km correspond to models by Kondratiev, et al., (ref. 50), Wark, et al., said their 15 micron values was much higher than that of Kondratiev, et al., because they selected a higher level as the top of the air column over which they integrated the radiative transfer equation. Wark, et al., also found by upward extrapolation of other profiles that the Hanel, et al., (ref. 54) and Oppel, G. E. and Burn J. W. (private communication to Wark) maximum tangent heights of radiance would be about five km higher and lower, respectively, than the Wark, et al., value of 65 km.

The Radiance Profile as a Whole

Since there is no simple way of representing analytically the profile of radiance versus tangent height from theory, Burn (ref. 64) developed an empirical formula for radiance in the following form:

$$N = A \times 10^{-4} \left[1 + e^{BZ} \times 10^{-4} \right]^{-\frac{1}{2}}$$

where A and B are coefficients which assume different constant values for four different model atmospheres. The formula gave the best fit to computed radiance values in the Arctic winter air mass, which has the smallest amount of water vapor, the presumed cause of the discrepancies in the other air mass models. A more elaborate profile formula of an exponential nature was presented in Reference 49.

The temperatures, averaged over the range of pressure values corresponding to a selected range of tangent heights, yield a pressure weighted averaged defined by Wark, et al.(ref. 55) as the effective temperature. However, Kondratiev and Yakushevskaya (ref. 60) defined the effective temperature and pressure as their values at the level where the radiance equals the average radiance. The existence of this level is prescribed by the mean value theorem. Kondratiev and Yakushevskaya (ref. 60) prepared a table of effective temperatures and pressures for the whole air column of each of three different air masses and for each of six intervals one micron wide between 12 and 18 microns.

VARIATIONS IN RADIANCE PROFILES WITH INDEPENDENT PARAMETERS

The horizon radiance values which constitute the profiles depend on a great many parameters. They will be treated individually in this report as if they were mathematically independent variables in their effects on the dependent variable, radiance. These parameters in actuality are not strictly independent of each other, since they are generally mutually related through physical laws.

Temperature

Temperature is one of the most important factors affecting radiance. The Planck function shows that all wavelengths, emission increases as the temperature increases. It also shows that this increase is less rapid in the far infrared than in the near infrared due to a temperature increase shifting the maximum radiation's wavelength, which, by Wien's Displacement Law is inversely proportional to absolute temperature, away from the far toward the near infrared.

The effects of perturbations in temperature and its lapse rate on horizon radiance profiles were studied by Honeywell (ref. 49). Variations of computed radiance within each of 10 spectral subintervals were artificially introduced by time changes in atmospheric temperature and its vertical derivative.

The tropopause, which is defined by the relatively cold boundary between the troposphere and stratosphere, will affect the horizon radiance profile under certain conditions. Kondratiev and Yakushevskaya (ref. 50) identified the tropopause with the bottom of the steep negative slope of their profiles of 12-18 micron emission. It also appeared as a dip in the radiance profile (ref. 49), when the subinterval of 600-615 cm^{-1} (16.26-16.67 microns), characterized by weak carbon dioxide absorption, was added to the spectral interval of 615-715 cm^{-1} (13.99-16.26 microns), corresponding to strong absorption which did not show the tropopause. When clouds are assumed to be at or above the tropopause, as in the tropical model soundings of Burn (ref. 64) and Hanel, et al., (ref. 56), they play the role of dominating radiators (ref. 63). They may increase the radiance at 10 km and decrease it at 0 km (ref. 4). In the absence of these clouds, McGee (ref. 63) assumed that the Earth will still appear to be radiating with an effective temperature near the tropopause. In normal situations where the tropopause lowers with increasing latitude or with time, there is a downward shift in the tangent heights corresponding to the maximum negative slope and adjacent features of the radiance profile (ref. 50). This is particularly pronounced in the case of sudden stratospheric warmings (refs. 11 and 49), which normally occur in the polar regions in the late winter. As the pronounced warming patterns descend and move toward lower latitudes, they cause the radiance profiles to change shape as well as to descend. Their probable effects would be to stretch the profiles and cause the general level of radiance values to increase. The disturbance caused by the sudden stratospheric warming may last a month or more.

Atmospheric Water Substances

In narrow spectral regions of very intense absorption lines, the radiance profile does not depend on the amount of cloudiness, according to Kondratiev and Yakushevskaya (ref. 50). For their wavelength interval of 12-18 microns, the effect of cloudiness diminished the radiance. This effect was noticeable, but not great, only for clouds in the tropics viewed at low nadir angles (ref. 56). The profile is flatter for cloudy conditions than for clear skies and clouds, partly cloudy skies will not disturb the uniformity of the radiance profile (ref. 50). In particular, clouds in the ARDC models will likewise have no effect at 13.6 microns (ref. 63). Clouds cause scattering, which tends to reduce transmission (ref. 51), but the effect is negligible at 15 microns.

The heights of cloud tops are important (ref. 51) since they relate to the temperatures at which they radiate. Hanel, et al., (ref. 56) Honeywell (ref. 49), and Kondratiev and Yakushevskaya (ref. 60) studied the effects of cloud tops at many altitudes in the troposphere. In the Honeywell study, the clouds were found to have no effects on radiance profiles when the stratification was isothermal, but the effects varied in magnitude for non-isothermal cases. Kondratiev and Yakushevskaya found that the radiance profile was somewhat flatter for cloud tops at nine km than those at three km. McArthur (ref. 58) found that the emissivity in the 14-16 micron region became unity at 20 km, which is significantly above the normal cloud top level. If this is true, clouds will have no effect at all on the radiance profile.

Water vapor diminishes transmissivity by absorption, particularly in portions of the spectrum where the carbon dioxide absorption is weak. It also tends to flatten radiance profiles near the horizon, but this effect is negligible in the 15 micron carbon dioxide band (ref. 50).

Consequently, water substances play a minor role, compared with temperature, in the narrow region of the spectrum around 15 microns.

Circulation (Atmospheric Wind and Pressure)

Honeywell (ref. 89) studied the relationship between horizon radiance profiles and the circulation parameters, jet stream (wind parameters) and trough and ridge (pressure parameters). No correlation between profile variations and circulation parameter variations could be found.

Spatial Parameters

Latitude and geographical variations were considered by most investigators, who included polar, temperature, and tropical air mass models. Kondratiev and Yakushevskaya (ref. 50) found that the differences between radiance profiles for the equator and 65° latitude were comparable with the differences between profiles for clear skies and cloud tops at three km, but less than the differences between clear skies and cloud tops at nine km. The radiance at 65° latitude generally exceeded that at 0°, but limb darkening at 65° was less at the equator. Kondratiev and Yakushevskaya (ref. 60) reported that the effects of latitude variations were smaller than the effects of seasonal variations at middle latitudes. McArthur (ref. 58) noted that the radiance varied markedly with latitude, increasing poleward in summer and equatorward in winter. The latitude effects operate through variations in high-level temperature lapse rates and in the height of the top of the atmosphere (defined by an isobaric surface of low pressure), which is higher over warmer air columns than cold air columns, (ref. 49).

Other spatial variables were introduced by the view of the sensor, namely, the azimuth toward which it is pointed and the angular radius of the cone which it detected. Since meteorological conditions are assumed to vary more in latitude than longitude, a variable-azimuth scan is assumed to show differences between north and south facings, but not east and west facings. Azimuthal uniformity for the sensor was assumed by Hanel, et al.,(ref. 54), Kondratiev and Yakushevskaya (ref. 50) took latitudinal asymmetry into account for the view of a sensor looking north and south from a single location.

The effect of sensing over a circular area 3° in diameter is that the intensities of different magnitudes are averaged. The result is that the radiance profile of averaged values is flattened, particularly near the horizon, where large contrasts in intensity are present within the field of view (ref. 50). Since the Tiros VII radiometer sights over a 5° field of view, its measurements are not comparable with theoretical narrow rays (refs. 55 and 58), and cannot be used for direct checking of the computed radiances.

Time Parameters

The principal regular time variables are the annual (seasonal) and diurnal cycles. Most time variations have to be classed as irregular.

The annual variations of radiance profiles were obtained by most investigators (refs. 50, 53, 56, 58, and 64) by use of the extreme seasons represented by

January and July. An improvement was made by Honeywell (refs. 11, 49, 90, 91, and 89) which introduced all four seasons represented by eight synoptic situations over a wide geographic area. It was noted that changes between the winter and summer half years occurred near the equinoxes, when latitudinal regularity of horizontal temperature gradients breaks down and the temperature patterns become weak.

Diurnal variations were studied by Honeywell (ref. 89), McArthur (ref. 58), and Oppel and Pearson (ref. 54). Only small effects were noted by Honeywell. McArthur established the phase of the diurnal variation radiance at 20, 30, 40 and 55 km as giving maximum and minimum radiances at 1400 and 0200 local time, respectively. The amplitude of the variation diminished with increasing altitude above 30 km, primarily because the radiance itself diminished with increasing height.

Irregular time variations are best exemplified by the explosive warmings of the polar stratosphere in winter. The resulting large temporal variations have been studied by Duncan, et al., (ref. 53). Hanel, et al., (ref. 56) and McArthur (ref. 58) both noted parameters not subject to irregular variations: the Arctic winter radiance and the carbon dioxide concentration, respectively.

Wavelengths (Or Wave Numbers)

The variations in wavelength were too wide in some cases (refs. 55 and 60) to apply to this study. The character of the 12-18 micron radiance profile of Kondratiev and Yakushevskaya (ref. 60) was significantly different from the 14-16 micron radiance, because the former received emission from much lower in the atmosphere, where there were variable meteorological influences. Wark, et al., (ref. 55) covered wavelengths longer than 4.29 microns, where there were tremendous variations with change of wavelength. Earle (ref. 87) justified the use of the 15 micron band in preference to other carbon dioxide and water vapor bands in the infrared: 2.7 microns of H_2O and CO_2, 4.3 microns of CO_2, 6.3 microns of H_2O, and 20-40 microns of H_2O. The comparisons made between subintervals of the 15 micron CO_2 band by Honeywell (ref. 49), were useful in defining the best limits to pick for the whold interval encompassing the band.

EXPERIMENTAL PROGRAMS

INTRODUCTION

Several experimental programs measuring the infrared radiation from the earth have been conducted. Although few programs have actually made measurements directly on the Earth's 15μ CO_2 horizon, all of these programs have contributed to the total knowledge of the CO_2 radiation mechanisms. Horizon sensors were first flown in 1958. As problems with erratic operation developed, interest in making measurements on the infrared horizon increased.

NASA/Langley Research Center (LRC) started the D-61 program in 1961 to examine various infrared spectral regions. This program, only partially successful, showed that the horizon profiles shape and altitude varied considerably with spectral region. Lockheed conducted the IRATE program under Air Force sponsorship in 1962. This program made measurements in five spectral bands including the 14-16μ band and showed the improvements possible in horizon sensing from this band. Also in 1962, Eastman Kodak under Air Force sponsorship flew a radiometer system to make comparative measurements on three μ, two μ, and one μ bandwidths centered around 15 μ. The narrowest bandwidth showed the least variations. In June, 1963, the Tiros VII weather satellite was launched by NASA/Goddard Space Flight Center (GSFC). Included in the payload was a five-channel, medium resolution infrared radiometer, one channel of which responded to the 14. 8 to 15. 5μ region. Although noise problems and field of view considerations did not allow horizon shape analysis, analysis of the long term variations of radiance in the 15μ band was accomplished because of the satellite's long lifetime. NASA/LRC is operating a continuing program using the X-15 aircraft to carry radiometers to altitudes sufficient for making horizon radiance measurements. This program, although limited in spectral interval and quantity, has provided the highest resolution and spatial positioning measurements on infrared horizon profiles to date. The Nimbus II weather satellite launched in May, 1966, by NASA/GSFC had a five-channel radiometer, similar to the Tiros VII vehicle, with one channel responding in the 14 to 16μ band. Resolution and scan rates limit horizon shape analysis; however, the high quality and quantity of the data does allow for analysis of many short term variations in the CO_2 peak radiance.

Measurements on infrared radiance of the atmosphere including the 15μ band have been made from both ground and balloon-borne systems. Although these systems are not capable of making measurements similar to what satellites would see, they do provide confirmation of radiance models and input data and insight into the possible radiance variations which a satellite would see.

Some insight to the variations of the infrared horizon can be attained by directly examining recorded horizon sensor data from satellites. In most cases, satellites using horizon sensors for attitude control have no other device for determining attitude. Thus, it is usually only possible to say that a variation has occurred, not what its magnitude or precise cause was.

No system in a satellite has yet been flown which made high resolution, high spatial accuracy measurements on the 14 to 16μ horizon of the Earth. To reach the ultimate attitude measurement accuracies of horizon sensors, it is essential that a program to measure the variations in the CO_2 horizon be conducted. The Scanner rocket probe, sponsored by Langley Research Center, launched in August, 1966, will provide a high horizon resolution [field of view (FOV) 0.025° by 0.10°] and a high spatial position accuracy (2 km) of the 14 to 16 μ horizon. However, since this program is scheduled to consist of only three ballistic flights from Wallops Island, Va., the analysis of variations of the horizon from this data will be limited.

It should be pointed out here that in reading this section it may erroneously appear that the programs were not successful because complete information on the 14 to 16μ band was not obtained. In most cases their objectives were not CO_2 horizon measurements, and information in this area is a by-product of their principle objectives.

D-61

The D-61 program was initiated by Langley Research Center in 1961 to make observations on the Earth's horizon in various spectral regions. Using a radiometer measuring four spectral intervals along the same line of sight comparative measurements of the radiance profile shapes and positions were planned. The vehicle was launched on ballistic trajectories to altitudes of 600 km from Wallops Island, Virginia. A total of three flights were made; however, only the first flight produced data. Flight 1 was made November 17, 1961, and is reported in Reference 92. Flight 2 was made in 1963; telemetry failed 29 seconds after launch, and no data was obtained. The third and last flight of the series, early 1966, had staging problems and was also not successful.

Flight 1 had problems that partially destroyed its usefulness for analysis of horizon variations. Spun up to 600 rpm during launch, a despin mechanism spun the vehicle down only to 400 rpm rather than the design goal of 40 rpm. This made it impossible to make accurate attitude measurements, and the horizon gradients could not be positioned with respect to the solid earth.

The spectral bands covered in this experiment were the near infrared (0.75 to 3.0 μ), visible (0.29 to 1.0 μ), ultraviolet (0.23 to 0.29μ), and the far infrared (1.8 to 25μ). The radiometer characteristics are given in Table 11 and the filter response curves are shown in Figures 27 and 28. A sample of the telemetered radiometer outputs is shown in Figure 29. Clouds tended to appear in all bands but with different spatial dimensions, indicating that different depths into the atmosphere are examined with each channel.

The peak radiance in the ultraviolet band of the horizon profile occurs high in the atmosphere, nominally 50 to 60 km. Although the magnitude of the peak varies considerably with sun angle, the altitude of the peak may be stable.

This program was the first work by LRC to make precision horizon measurements in the infrared region. Some indications of clouds and temperature gradients as a function of latitude were observed in the far infrared channel. It can be seen from Figure 29 that the horizon position shifts with different spectral intervals. Little information on the characteristics of the 14 to 16 μ CO_2 horizon can be deduced from this program.

TABLE 11. - D-61 RADIOMETER CHARACTERISTICS

	Ultraviolet	Visable	Near infrared	Far infrared
Spectral band	0.23μ to 0.29μ	0.29μ to 1.0μ	0.75μ to 3.0μ	1.8μ to 25μ
Focal length	25.4 cm	25.4 cm	25.4 cm	7.60 cm
Aperture	7.60-cm diameter	7.60-cm diameter	7.60-cm diameter	7.60-cm diameter
Detector	Photomultiplier	PbS (1 mm by 1 mm)	PbS (1 mm by 1 mm)	Thermistor bolometer (1 mm by 1 mm)
Filter	Composite filter (a)	Color filter (2.54 mm)	Color filter (2.54 mm)	Germanium (1 mm)
Channel time constant	< 0.0003 sec	< 0.0003 sec	< 0.0003 sec	0.001 sec
Field of view	0.22° by 0.22°	0.22° by 0.22°	0.22° by 0.22°	0.75° by 0.75°

[a] Contains $NiSO_4 \cdot 6H_2O$ (8 mm), Polyvinyl alcohol incorporating cation X, ultraviolet transmitting color filter (3 mm), and quartz (6 mm).

IRATE

The IRATE program conducted by Lockheed Missiles and Space Corp. (LMSC) for AF/SSD was the first orbital program to actually make measurements in the 14-16μ band.

The objectives of the program were to make comparative measurements of the Earth's horizon radiance in five spectral bands in the infrared to provide a basis for horizon sensor design and to obtain information on the relative levels of earth or meteorological noise for the various bands used. To make the measurements, five horizon sensors scanning on the same line of sight on the horizon were flown on a Discoverer satellite in July of 1962. The complete set of data obtained is described in Reference 93. The data taken provides an

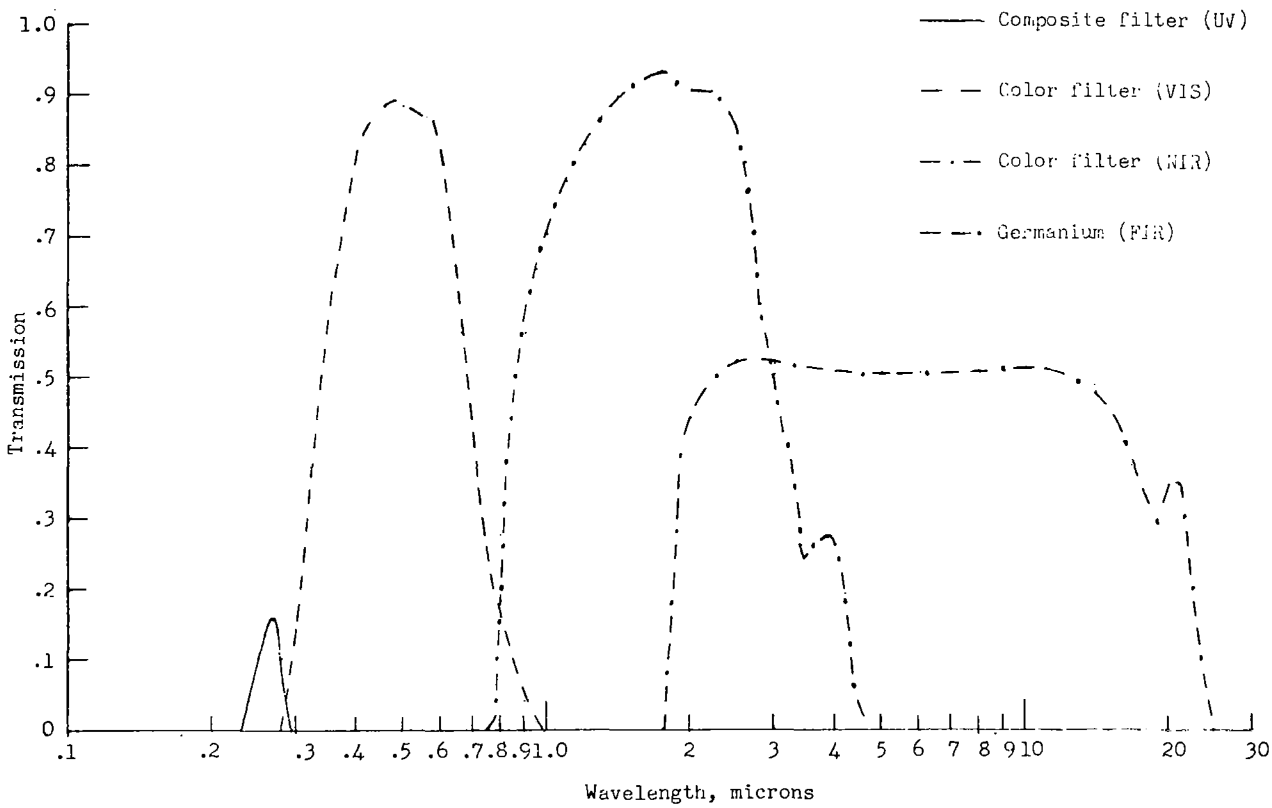


Figure 27. D-61 Transmission of Optical Filters
[From Ref. 92]

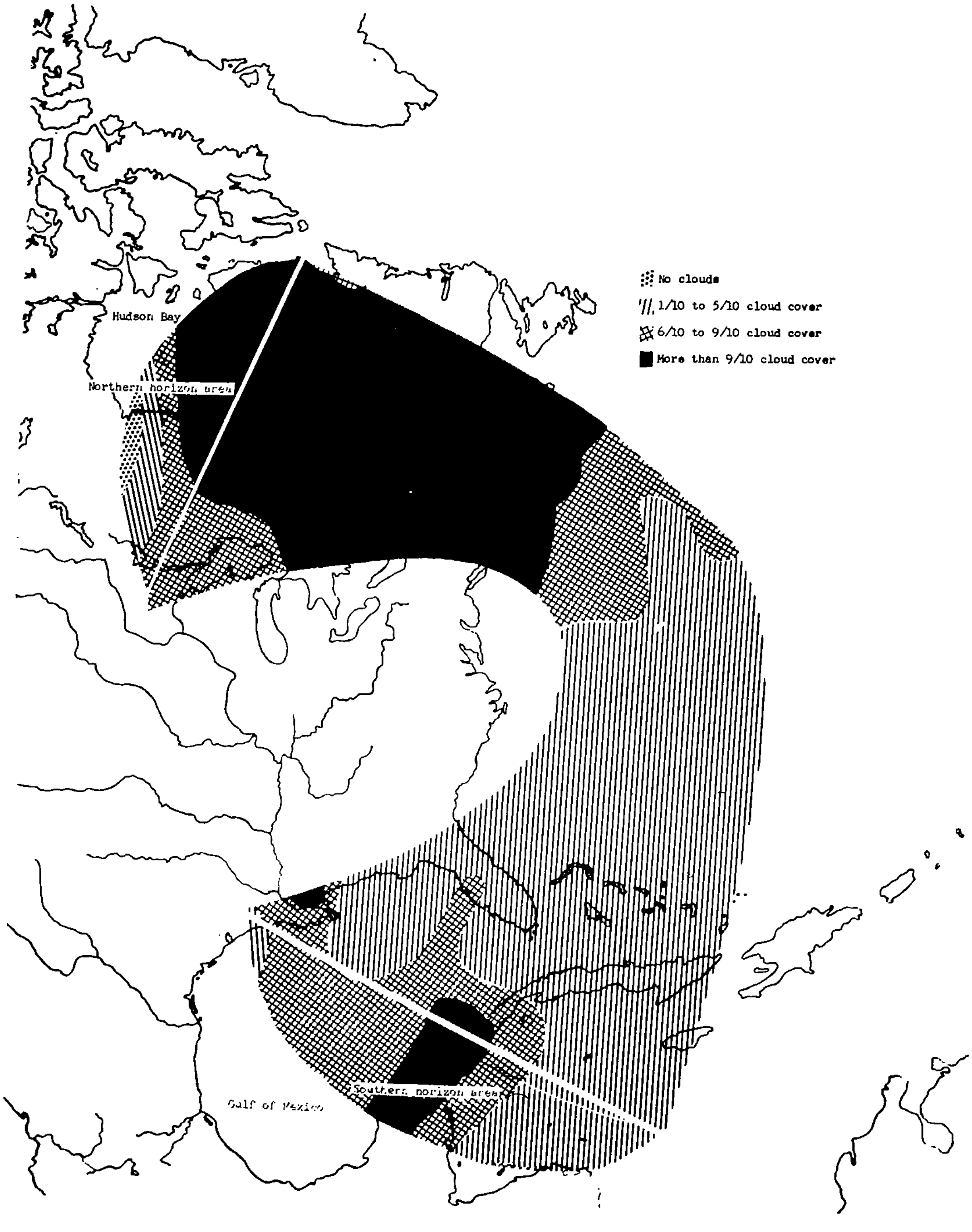
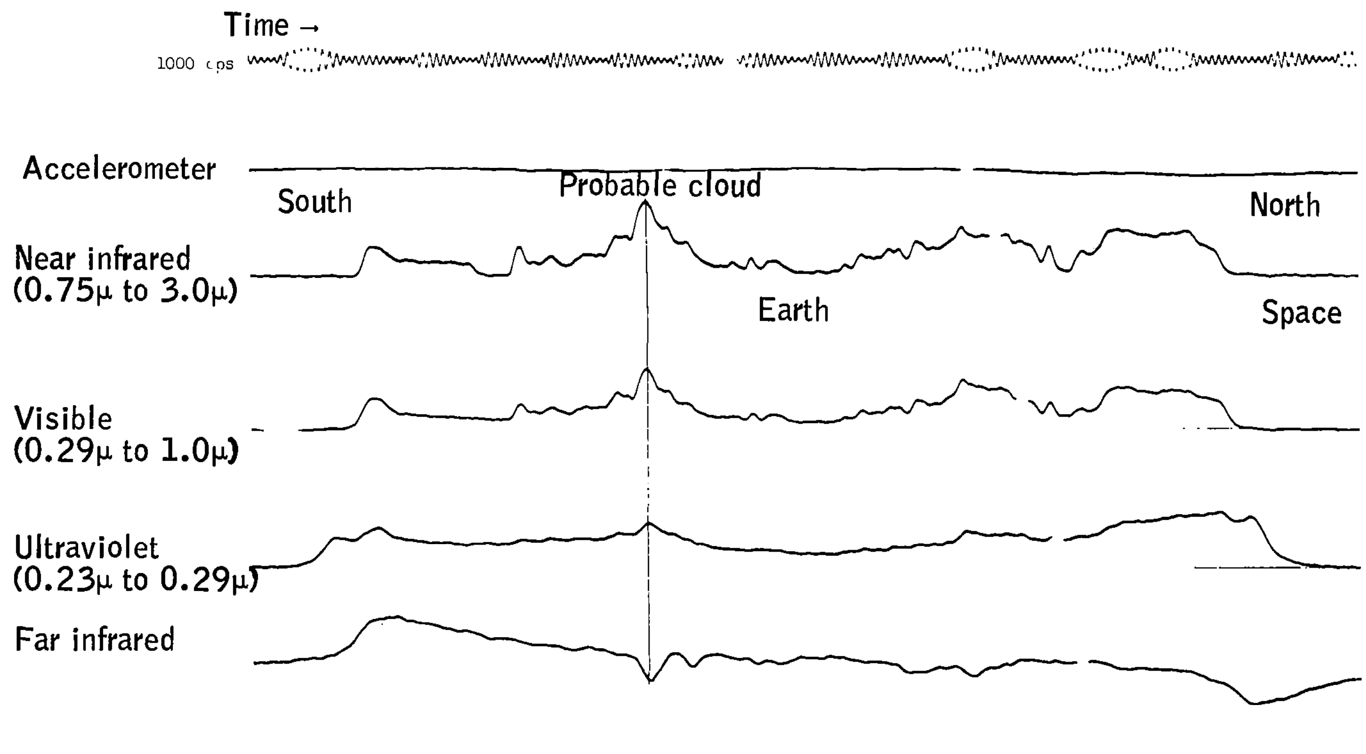


Figure 28. D-61 Total Cloud Cover in Scanned Regions [From Ref. 92]



(a) Vehicle altitude of 300 km.

Figure 29. D-61 Samples of Telemeter Record
[From Ref. 92]

effective argument that the 14 to 16 μ CO_2 band is a more stable band for horizon sensing than the 5 to 18, 12.5 to 18, 15 to 18, or 15 to 35 μ bands. In essentially all cases, the 14 to 16 μ spectral band showed a lower percentage of horizon anomalies and in addition a smaller temperature range of variation.

The characteristics of the horizon sensors are given in Table 12. The optical filter characteristics of the 14 to 16 μ band are shown in Figure 30. Unfortunately, the scan rate and field of view were such that definition of the true shape of the horizon could not be done. Conical scanning sensors were operated at 25 cps with a field of view of 4.77° x 0.97°. Small anomalies or horizon variations are effectively integrated out by this FOV. The detector time constant was 1.8 milliseconds. At the nominal altitude the CO_2 horizon was scanned in approximately 1 millisecond. The detector response was too slow to provide an accurate reproduction of the horizon shape. For this reason analysis of the data has been restricted primarily to comparisons between channels and magnitudes of the Earth's disc readings.

Examples of the sensor outputs, reproduced from Reference 93, are shown in Figures 31 and 32. Figure 31 shows the sensor outputs for essentially a "no-cloud" condition, while Figure 32 shows the outputs with a severe cloud effect on the trailing edge of the scan. It may be seen that clouds have much less effect on the 14 to 16μ sensor than on the other sensors. System noise varied considerably with time. Its amplitude can be determined by observing the space portion of the scan. On the 14 to 16μ channel, careful examination is required to separate actual cloud effects from the noise. Much of the random noise was removed by averaging several cycles of the wave forms. From the smoothed outputs, examples of which are shown in Figure 33, it was then possible to define an average peak temperature or radiance and a dropout (anomaly) term. Dropout is defined as the percentage loss of energy of the peak value of radiance. Dropout is attributed primarily to high clouds, although other atmospheric anomalies may cause similar effects. The comparative effects of clouds on the spectral intervals can be examined using the dropout term.

Some analysis of the data and comparison to computed radiance models are given by Bradfield (ref. 93) and Burn (ref. 94). Comparison of measured to computed variation of radiance in the 14 to 16 μ band shows good agreement. The analysis consists of comparing anomalies in the 14 to 16 μ band channel with the "reference" 5 to 18 μ channel. The latter channel provides a rough indication of the extent of cloudiness in the atmosphere. Only statistical information on number of occurrences can be derived since cloud heights and spatial dimensions cannot be obtained.

A summary chart in Figure 34 shows the percent of samples with dropout by channel and the magnitude of the anomaly. This chart was obtained in private correspondence with R. Fowler of Ithaco, Inc. It shows clearly the improvement in reducing cloud effects by narrowing the spectral response.

Data taking for the flight was limited to areas over five tracking stations and a total of 57 acquisitions during a time period of 95 orbits (approximately six days). No recording of data on the vehicle was done. The five stations were Vandenburg AFB, California; New Hampshire; Hawaii; Kodiak, Alaska; and

TABLE 12. -IRATE HORIZON SENSOR CHARACTERISTICS

[From ref. 93]

1.	Field of view	
	$4.77° \times .97°$ (5-18μ, 12.5-18μ, 14-16μ, 15-18μ)	
	$1/2° \times 1/8°$ (15-35μ)	
2.	Preamplifier gain at 25°C	
	5-18μ	475
	15-18μ	1667
	12.5-18μ	1400
	14-16μ	1667
	15-35μ	10 000
3.	Bolometer (+25°C)	
	Resistance	54k ohms ±15 percent
	Responsivity	100V/watt minimum
	NEP	2×10^{-9} at 100 cps
	Time constant	1.8 ± 0.3 milliseconds
	Flake material	No. 2
	Size	0.5 MM x 0.1 MM
	Coating	15μ peaked anti-reflective (no coating for 15-35)
	Bias	±17.1 Vdc

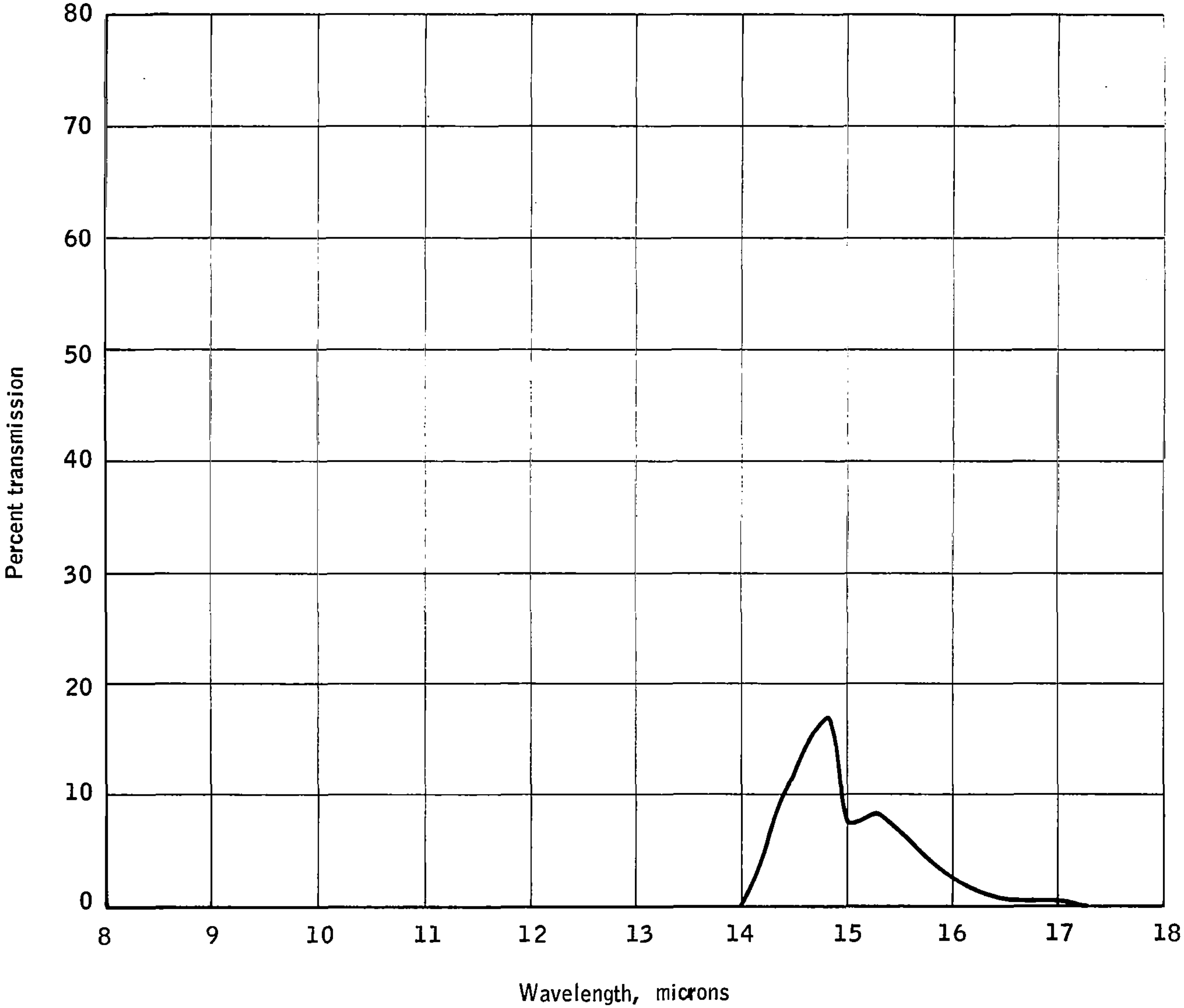


Figure 30. IRATE 14-16 Micron Total Optical Transmission
[From Ref. 93]

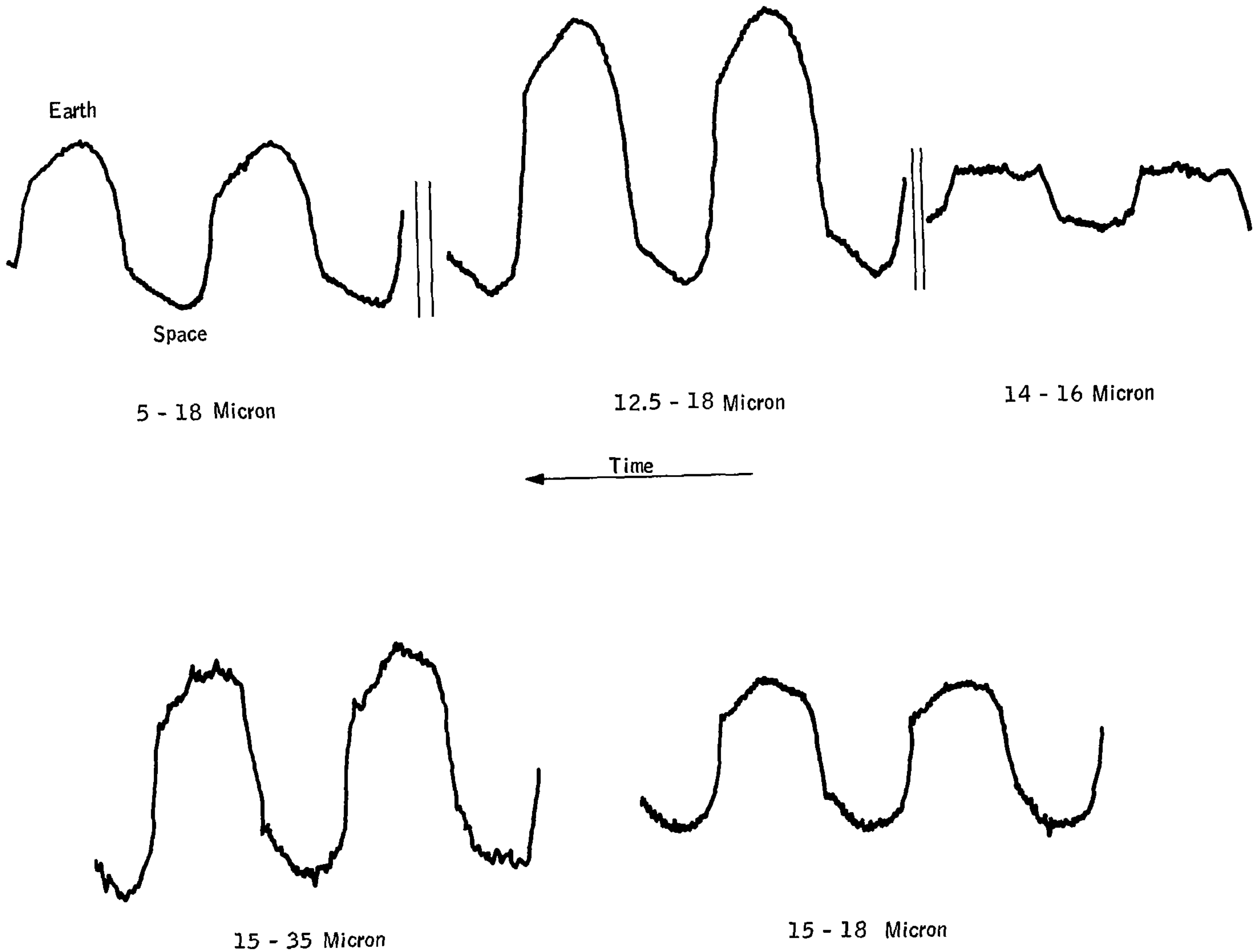


Figure 31. IRATE Sample Outputs, Clear Sky
[From Ref. 93]

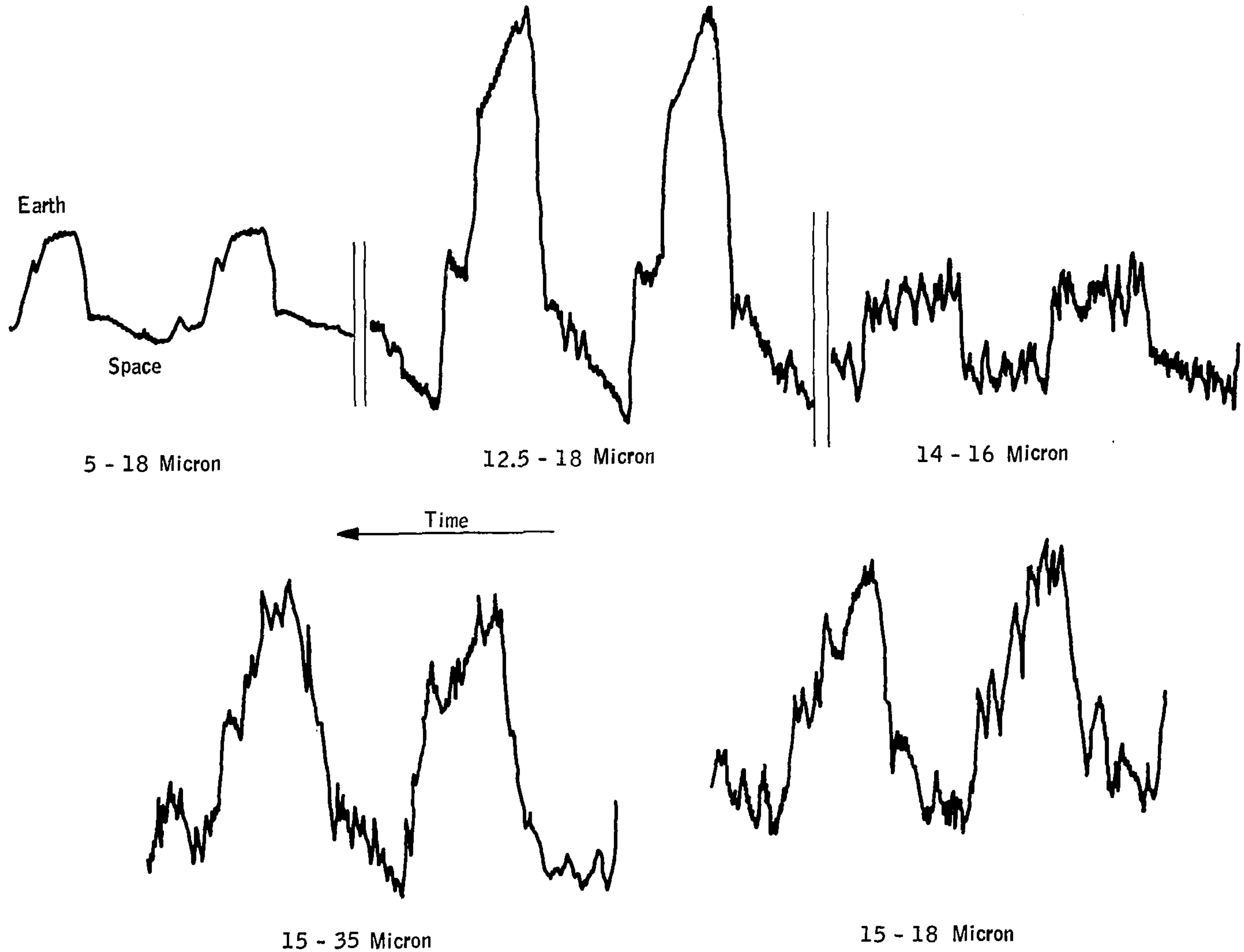


Figure 32. IRATE Sample Output, Cloud Effects
[From Ref. 93]

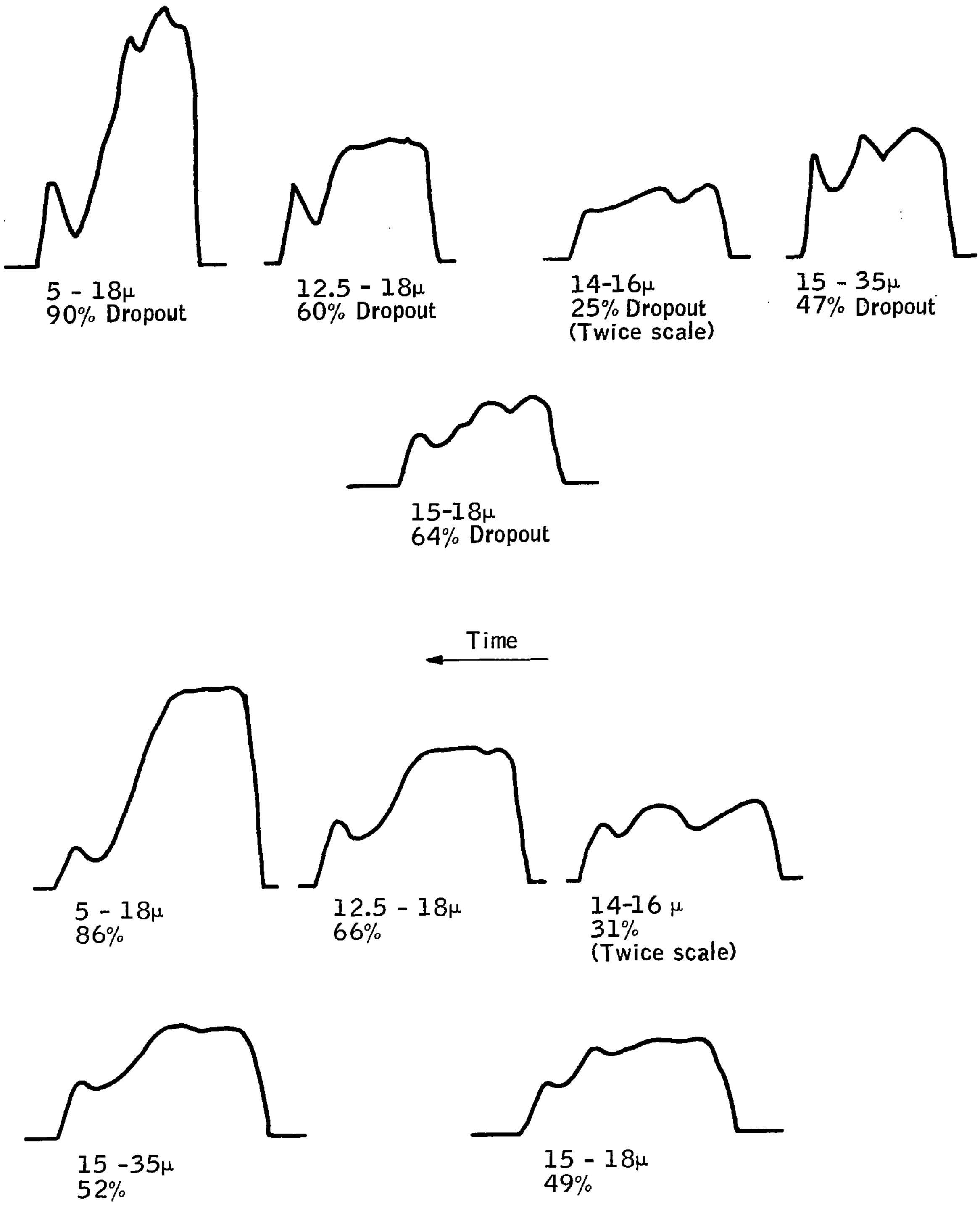


Figure 33. IRATE Processed Outputs
[From Ref. 93]

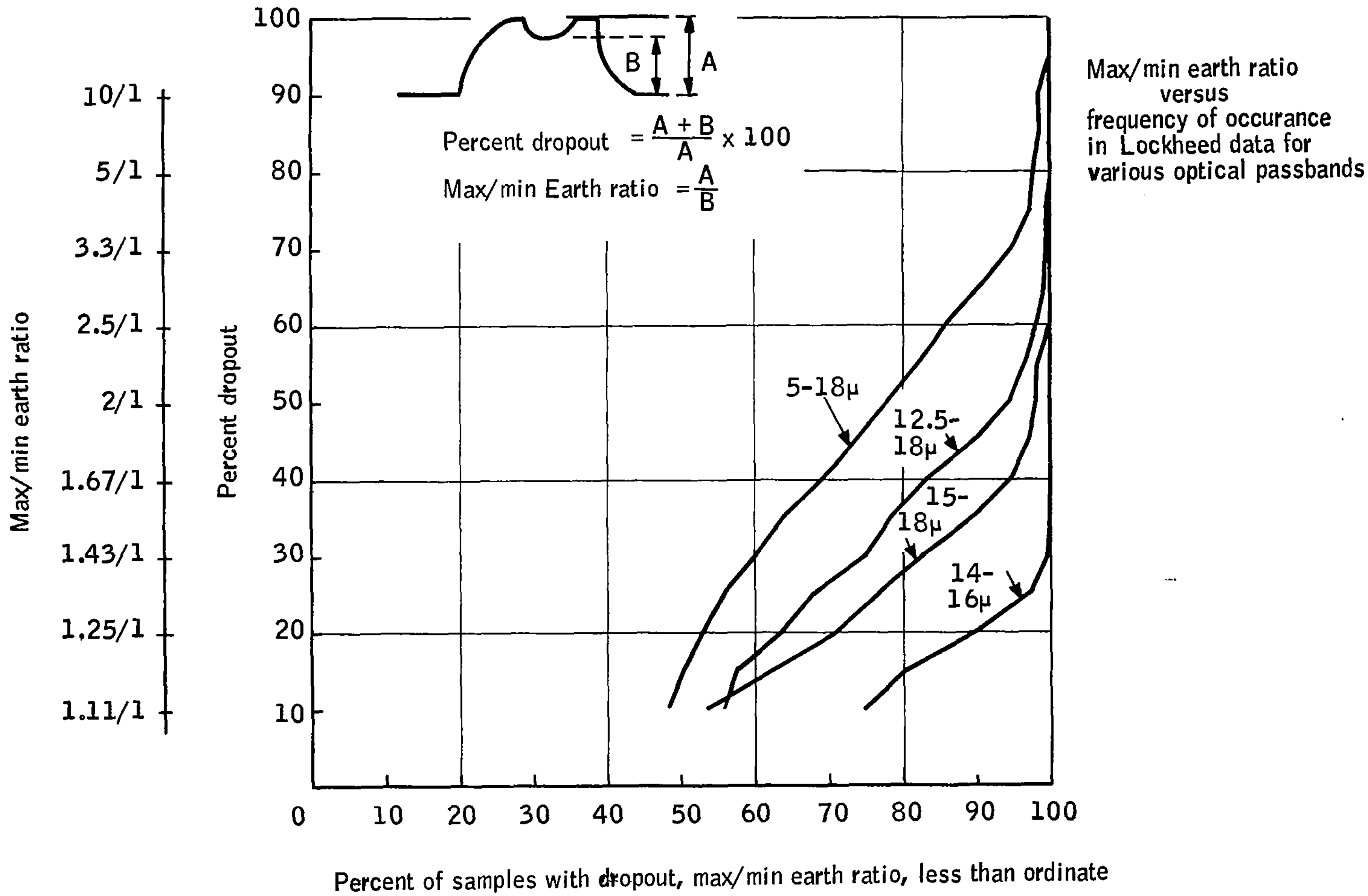


Figure 34. IRATE Channel Comparisons

Ascension Island. To determine if there were any temperature gradients as a function of latitude, the data for the 14 to 16 μ spectral band from each station was separated out and averaged. This is shown in Table 13. The latitudes given are those of the tracking stations and only roughly estimate the true latitude of the sensor view point.

TABLE 13. - IRATE 14 TO 16 μ DATA AS A FUNCTION OF LATITUDE

Tracking Station	Latitude	Temperature range	Average	% dropout
Ascension Island	8° S	215-220° K	216°K	9.5%
Hawaii	22° N	215-230° K	221°K	47%
Vandenburg	34° N	215-235° K	221°K	19%
New Hampshire	43° N	210-230° K	220°K	64%
Kodiak, Alaska	58° N	215-230° K	219°K	47%

No gradient of significance is apparent from the averages although the average for Ascension Island is lower than the other stations. According to data from Tiros VII, Eastman Kodak, and Nimbus II, which are described in this report, a strong seasonal or latitude temperature gradient should occur. It is possible with the limited quantities of data that local weather variations tended to mask out the latitude variation.

The percentage dropout by station varies considerably. This is reasonable in that clouds, if in an area, may remain for a good fraction of a six-day flight time. For example, it appears that clear weather prevailed over Ascension Island throughout the flight. Predominantly clear weather over Vandenburg AFB is indicated since only on orbit 94 was there any significant dropout there. For cases with anomalies, 96 percent of the readings in the 14 to 16 μ spectral band showed a lower percentage of anomaly than any of the other spectral bands measured.

The program showed that the 14 to 16 μ CO_2 band has significant advantages over the other four spectral bands measured. The 14 to 16 μ band still showed that 39 percent of the samples taken contained some anomalies. The measured temperature spread was 210°K to 235°K, but the flight was of too short duration to consider these as true maximum values. In addition, too little data was taken to observe significant temperature gradients, diurnal variations, etc.

EASTMAN KODAK

In December, 1962, a radiometric system designed by Eastman Kodak was flown to make comparative measurements of spectral intervals in the 14 to 16μ region and to verify uniformity of the radiant emittance in the CO_2 band. Details of the system and data analysis are given in References 57 and 95. The flight was of short duration, recording data for approximately two days, over latitudes between 65°N and 65°S. Although true horizon shape and position could not be determined because of a poor signal-to-noise ratio and vehicle attitude uncertainties, comparisons between channels and gradient measurements on the peak amplitude at the horizon could be made.

The radiometric system consisted of two radiometers with each having two channels. The system characteristics are shown in Table 14. Radiometer A consisted of a one micron channel and a two micron channel. Radiometer B had a three micron channel and a two micron channel similar to A. The system spectral response for each of the channels is shown in Figure 35 and was measured across the spectral range of 2 to 24 microns. The curves are shown as a function of optical density which is defined as equal to

$$\log_{10}\left(\frac{1}{\text{transparency.}}\right)$$

The angular position of the Earth's horizon could not be determined accurately from this system because of uncertainty of the vehicle attitude. A precise attitude reference other than horizon sensing itself was not available to the experimenters.

Two problems associated with the vehicle caused difficulties and degrading of the data. The radiometer system was installed on the vehicle two days prior to launch and could not be checked out or recalibrated during that time. The vehicle was launched into a highly elliptical orbit at low altitude such that significant aerodynamic heating was observed at perigee. New calibration curves had to be estimated to correct for the large range of radiometer temperatures encountered.

Examples of the radiometer outputs showing effects of clouds are given in Figure 36. From this figure it can be seen that little information on horizon shapes can be derived from the data .

Comparisons of the three bandwidths showed that the narrower channels were least susceptible to signal anomalies (short term decreases in radiant emittance). From an examination of the response characteristics all of the channels cut off sharply at 13.6 to 14.0 μ. The variation in response occurs principally on the long wavelength side with the two and three μ channels expanding toward the water vapor band. Assuming the anomalies are due to high clouds on the horizon it would be expected that the three μ channel would show more dropout than the two μ channel and the two μ channel more than the one μ channel. Measurable anomalies occurred on none of the one μ data, 20 percent of the two μ data, and 40 percent of the three micron data. Attempts made to correlate the anomalies with Tiros cloud data met with inconclusive results. Some correlation of anomalies with geographical features, such as continental coastlines, the Japanese Current, the Gulf Stream, etc. was observed. In most cases, the correlation was probably due to clouds which, on the average, tend to build up along the edges of these features.

TABLE 14.- KODAK SYSTEM PARAMETERS

	Radiometer A		Radiometer B	
	1 micron	2 microns	3 microns	2 microns
Spectral band	14.0-15.2μ	13.7-15.6μ	13.6-16.5μ	13.7-15.6μ
Top of scan	79.5°	84.0°	79.5°	84.0°
Bottom of scan	63.5°	68.0°	64.0°	68.5°
Commutator samples per scan	147	128	48	48
Scan time	6.1 sec.		5.25 sec.	
Direction of view	Side		Forward	
Field of view	0.2° x 2.0°		0.2° x 2.0°	

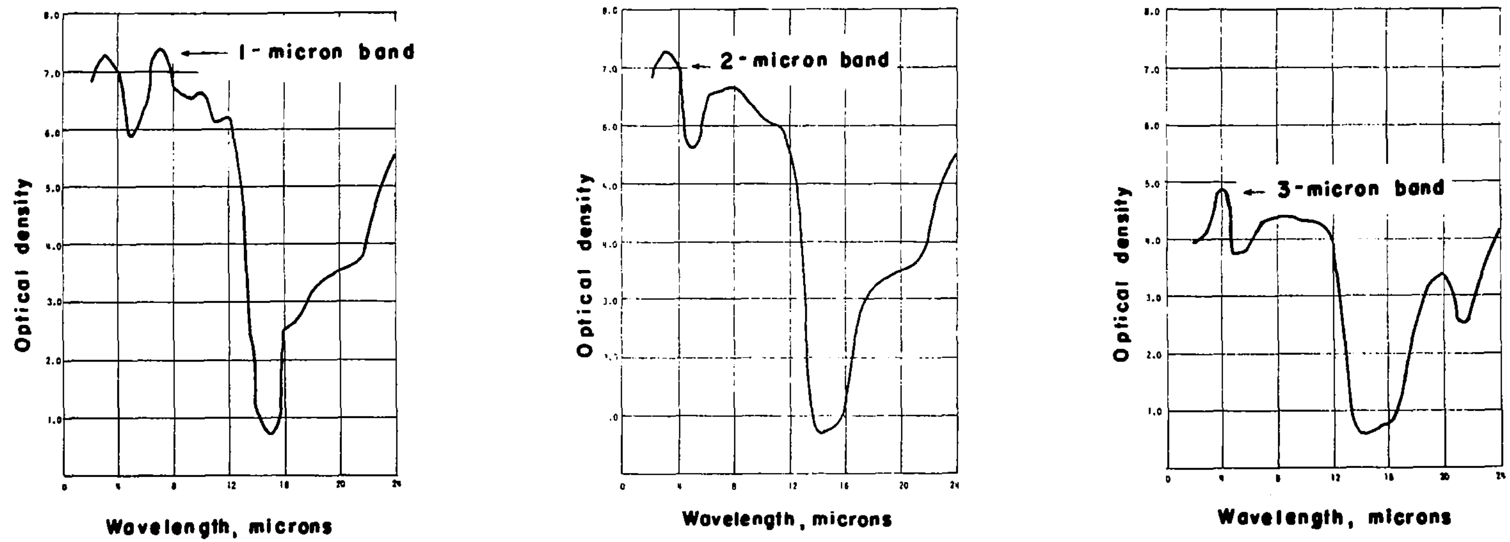


Figure 35. Kodak System Spectral Responses
[From Ref. 57]

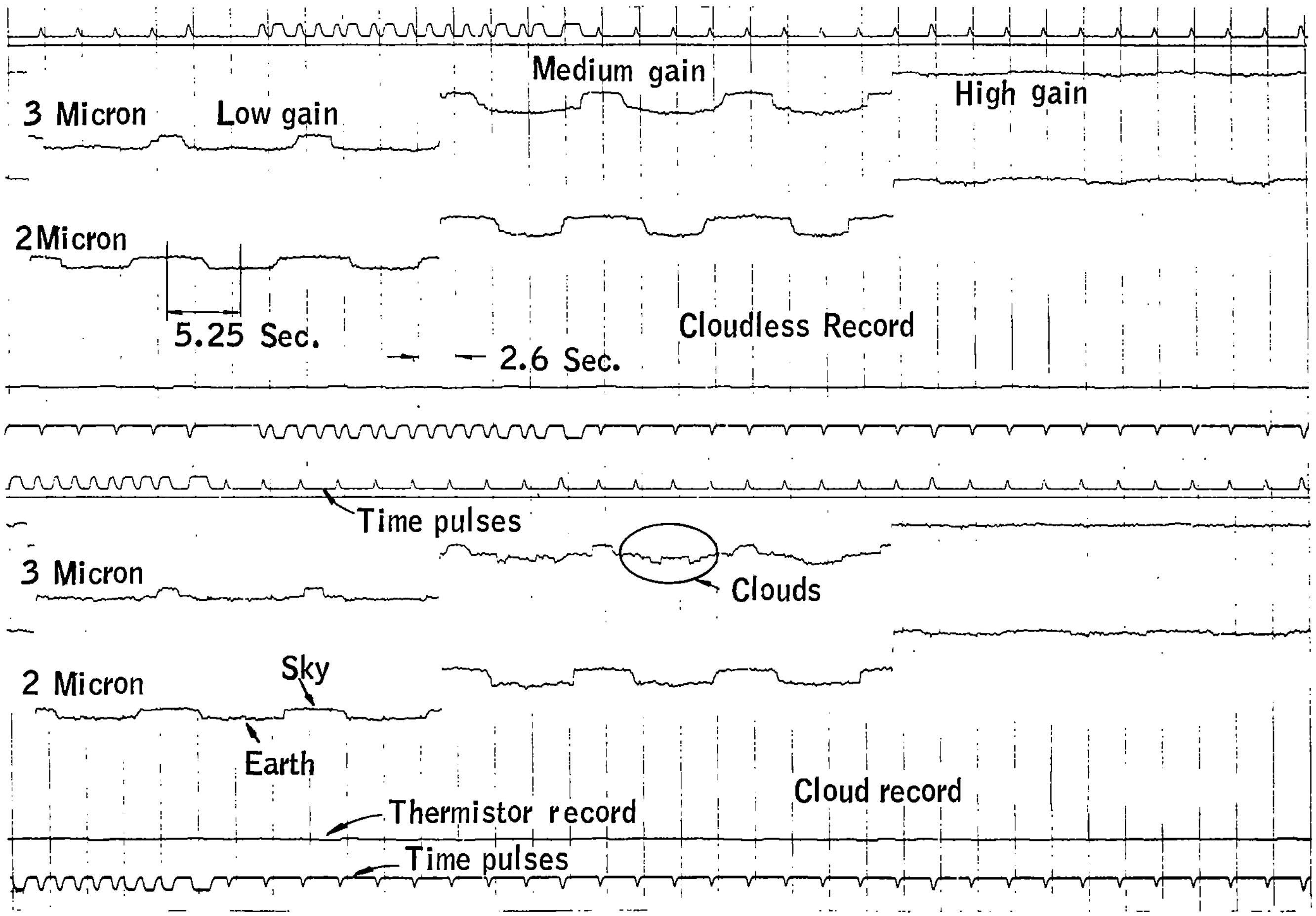


Figure 36. Kodak Example Outputs From "B" Radiometer
[From Ref. 57]

The peak radiance at the horizon plotted as a function of latitude in Figure 37 shows a significant gradient running from a minimum at the winter pole to a maximum at the summer pole. From the relatively small samples of data obtained here, the peak radiance increase from 65°N to 65°S latitude ranged from 10 to 20 percent of the mean radiance for each channel. This is a lower gradient than is commonly predicted in previous literature; however, it is approximately the same as was observed on Tiros VII (described in Tiros subsection) for winter in the Northern Hemisphere. The data was averaged independently of longitude thus removing the maximum gradients and showing the average gradient which can be expected. A relative minimum of radiance occurred near the equator to 20°S latitude. As can be seen in the Nimbus II data (described in Nimbus subsection), extensive high clouds in the intertropical convergence zone would tend to enhance this minimum when the data is averaged. In December, this zone would be in the 0° to 20°S latitude band.

No diurnal effect in peak radiance was noted from this experiment. Measured values between ±40° latitude were separated into day-night readings and averaged. With the amplitude resolution not better than 10 percent, it is very reasonable that diurnal effects were not observed. According to McArthur, (ref. 58) the maximum diurnal variation should not be greater than 10 percent of peak radiance, and with averaging as done here the variation would have been less than 5 percent.

TIROS

The Tiros series of weather satellites have contributed a significant quantity of data on the infrared radiation of the earth. Tiros II, III, IV, and VII all had medium resolution infrared radiometers (MRIR) as part of their payload along with the TV cameras in the visible region of the spectrum.

The MRIR responds to radiation in five different spectral regions. Three of the channels respond to emitted thermal radiation, and the other two channels respond to reflected solar radiation. The nominal wavelength intervals, their useful data lifetimes,and the launch dates for each satellite are shown in Table 15.

Tiros VII data is of principal interest to horizon sensing in that a channel was included to make measurements in the CO_2 absorption region and that its life-time was of sufficient length to examine seasonal variations in radiance. Tiros VII was launched June 19, 1963 from the Eastern Test Range with an angle of inclination of 58.2°. Its mean perigee and apogee altitudes respectively were 622 km and 648 km. Details of the MRIR experiment including calibrations and response characteristics for each channel are given in Reference 91. The response characteristic for the 15μ channel is reproduced here in Figure 38.

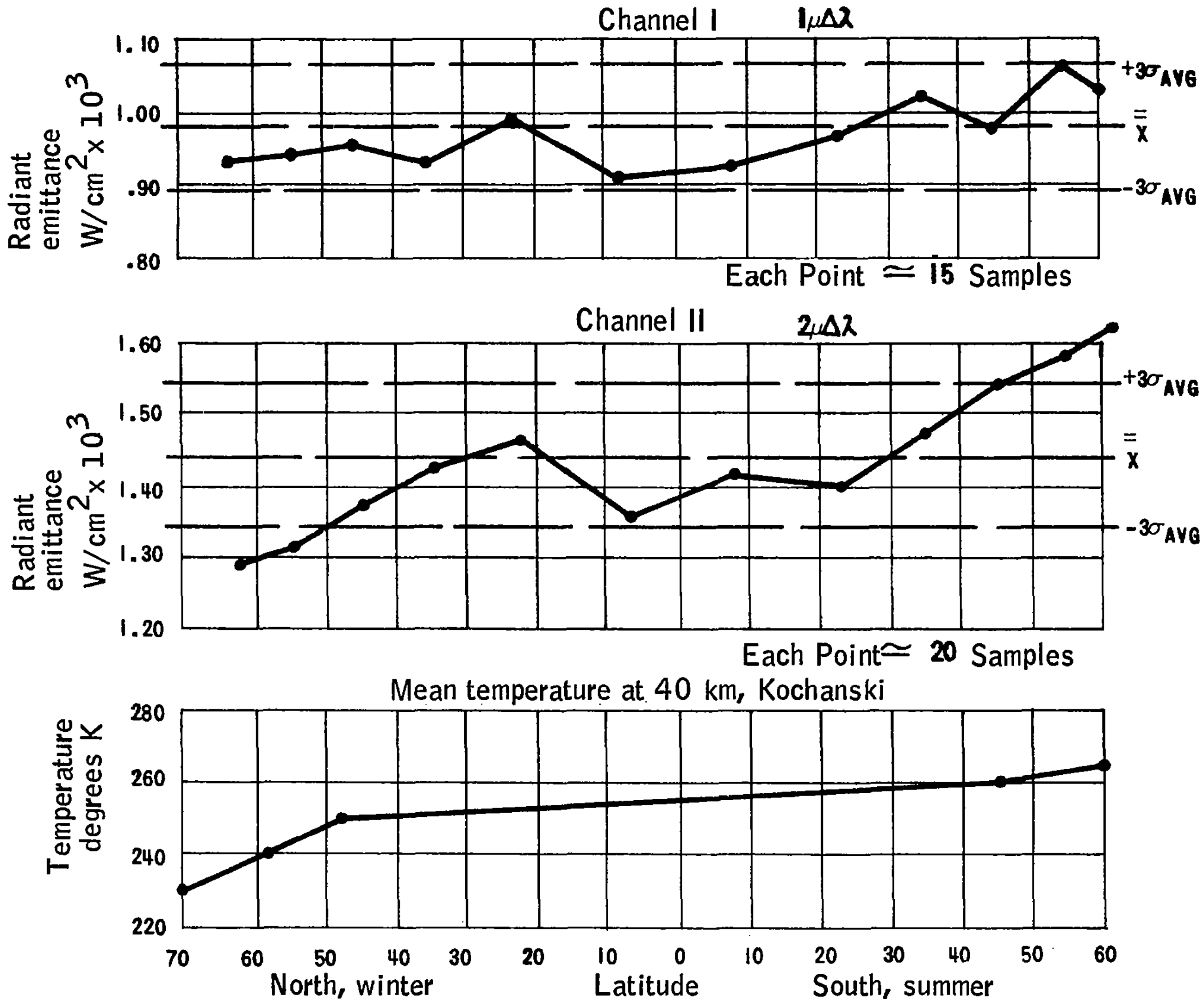


Figure 37. Kodak Latitude Effect, Radiometer A
[From Ref. 57]

TABLE 15. - NOMINAL WAVELENGTH INTERVALS OF TIROS RADIOMETER

Nominal wavelength interval	Satellite			
	Tiros II 11/23/60	Tiros III 7/12/61	Tiros IV 2/8/62	Tiros VII 6/19/63
6-6.5 μ (H_2O absorption)	X(1)	X(1)	X(5)	
8-12 μ (atmospheric window)	X(5)	X(2)	X(5)	X(17)
8-30 μ (long-wave radiation)	X(1)	X(1)		X(8)
14.8-15.5 μ (CO_2 absorption)				X(17)
0.2-6 μ (reflected solar radiation)	X(0)	X(2)	X(5)	X
0.55-0.75 μ (reflected solar radiation in the visible)	X(0)	X(1)	X(5)	X

The X's indicate channels which were included on each radiometer.
The numbers in parentheses indicate months of usable data.

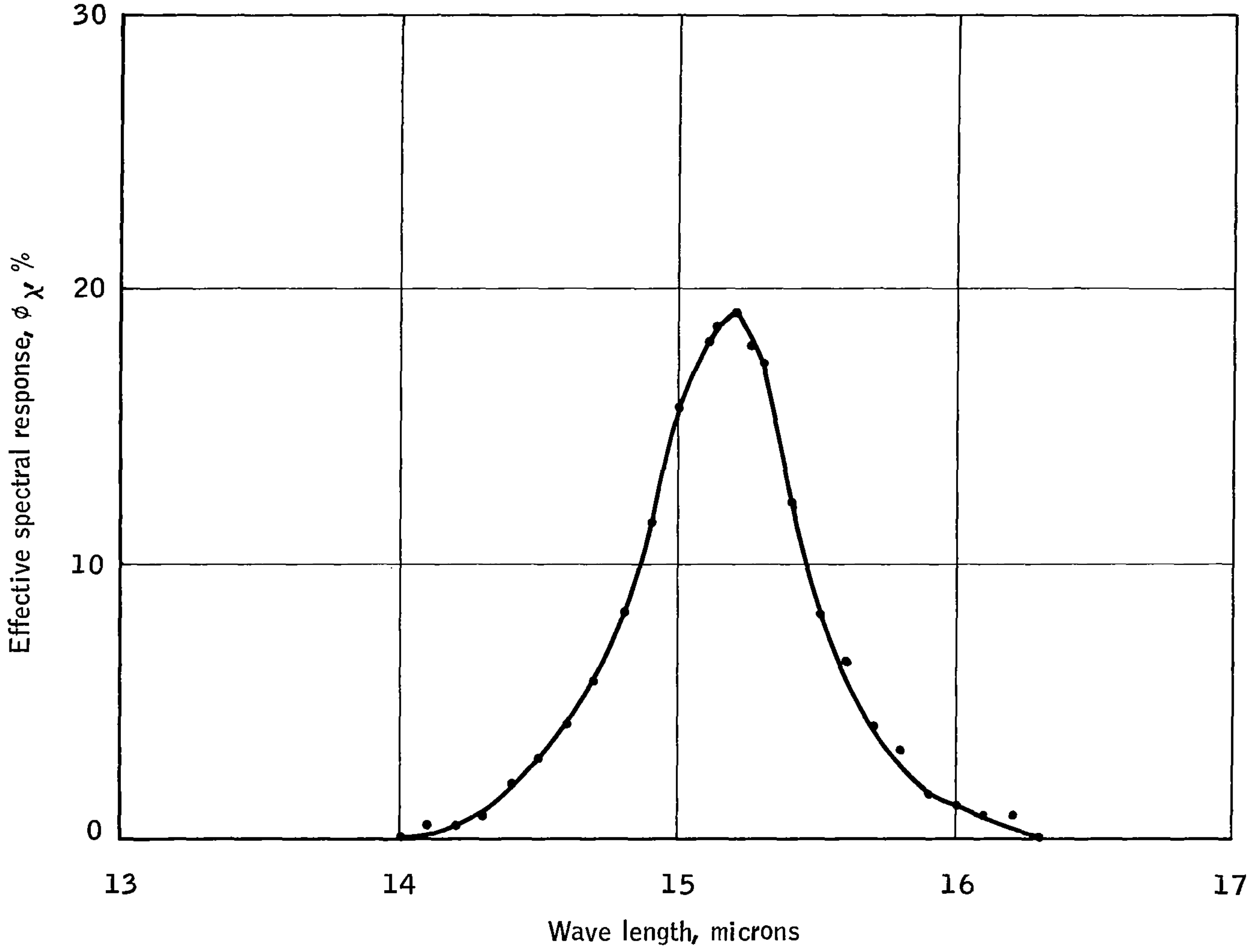


Figure 38. The Effective Spectral Response of Tiros VII 15μ Channel Versus Wavelength
[From Ref. 96]

Data from the MRIR is stored on the spacecraft on an endless loop magnetic tape with space for 100 minutes of storage. Because of the storage limit, data was lost on orbits where no contact with ground data acquisition stations could be made. In addition, data obtained in the vicinity of the tracking stations were sparse because no data recording was done during playback to the ground. The Earth's geographical area for which data were obtained is limited primarily to the area between 60°N and 60° S latitude because of the 58.2° inclination of the orbit plane. Three data acquisition stations were used: Fairbanks, Alaska; San Nicolas Island, Cal.; and Wallops Island, Va. Because only three stations were used and limited data storage was available on the spacecraft, data was sparse in two areas located at approximately 90° East and West longitude. The general area of data coverage is shown by the dashed lines in Figures 39 through 46. Small quantities of data at relatively high angles to the nadir are obtained outside the lines.

The Tiros vehicle is spin stabilized at a nominal six rpm. The MRIR optical axis is inclined 45° to the spin axis and has two viewing ports. When one optic views the Earth, the other optic views space. Chopping between the ports provides an output signal proportional to the difference in radiance viewed in the two directions. The radiometer scan pattern on the surface of the Earth is defined by the intersection of a 45° half-angle cone and a sphere. The pattern ranges from a circle to two hyperbola-like branches. Uncertainties in attitude lead to errors of from 1° to 2°. Viewing vertically downward (nadir angle = 0°), this corresponds to less than 20 miles position error but viewing toward the horizon this corresponds to position errors on the order of 200 miles. The field-of-view of the Tiros radiometer is approximately 5° at the 1/2 power points. Viewing vertically downward, the spatial resolution of the radiometer is approximately 55 km. Because of the attitude errors and the wide field-of-view, very little information on the true shape or position of the Earth's horizon can be obtained from the Tiros VII data. The information is primarily limited to measurements of radiance from the disk of the Earth within 40° of the nadir angle. Assuming no limb brightening or darkening, these measurements correspond to peak amplitudes of the horizon profiles. In general, the variations in the disk measurements should be similar to the variations in the peak amplitudes at the horizon.

The output of the 15μ channel is calibrated in terms of the temperature in degrees Kelvin of a black body filling the field-of-view of the radiometer. The techniques for deriving effective radiant emittance or radiance from the temperature values is described by Nordberg, Bandeen, Warnecke, and Kunde (ref. 97). Several changes in calibration have occurred for the 15μ data during the course of the flight due to electronic degradation and other unknown occurrences. After applying the known corrections, estimated short term relative accuracy of the temperature measurements are ± 2°K and absolute accuracy decreases linearly from ±7°K at launch (June 19, 1963) to ±12°K by 30 September 1964.

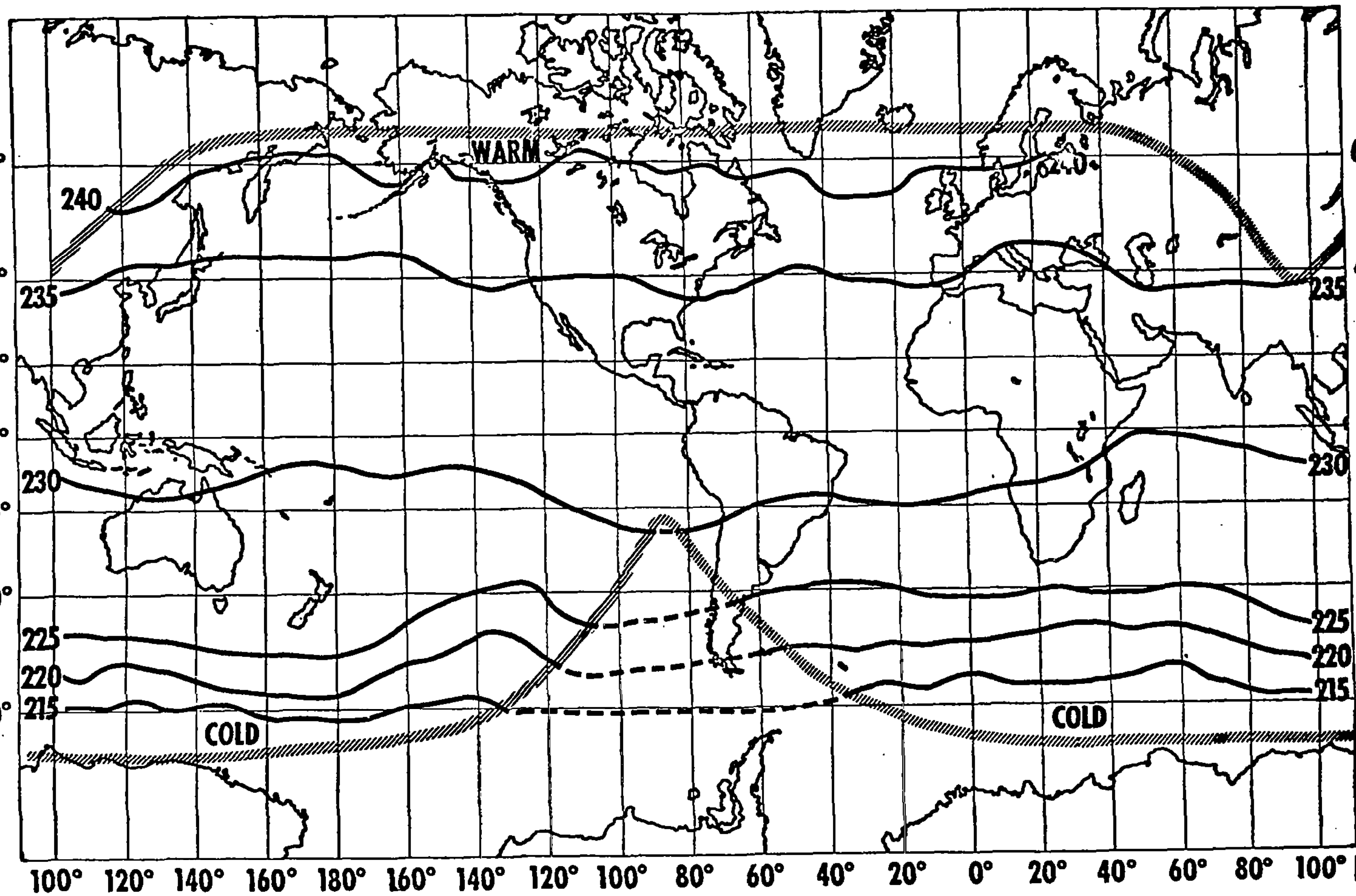


Figure 39. Tiros VII 15μ Isotherms 19-25 June 1963
[From Ref. 97]

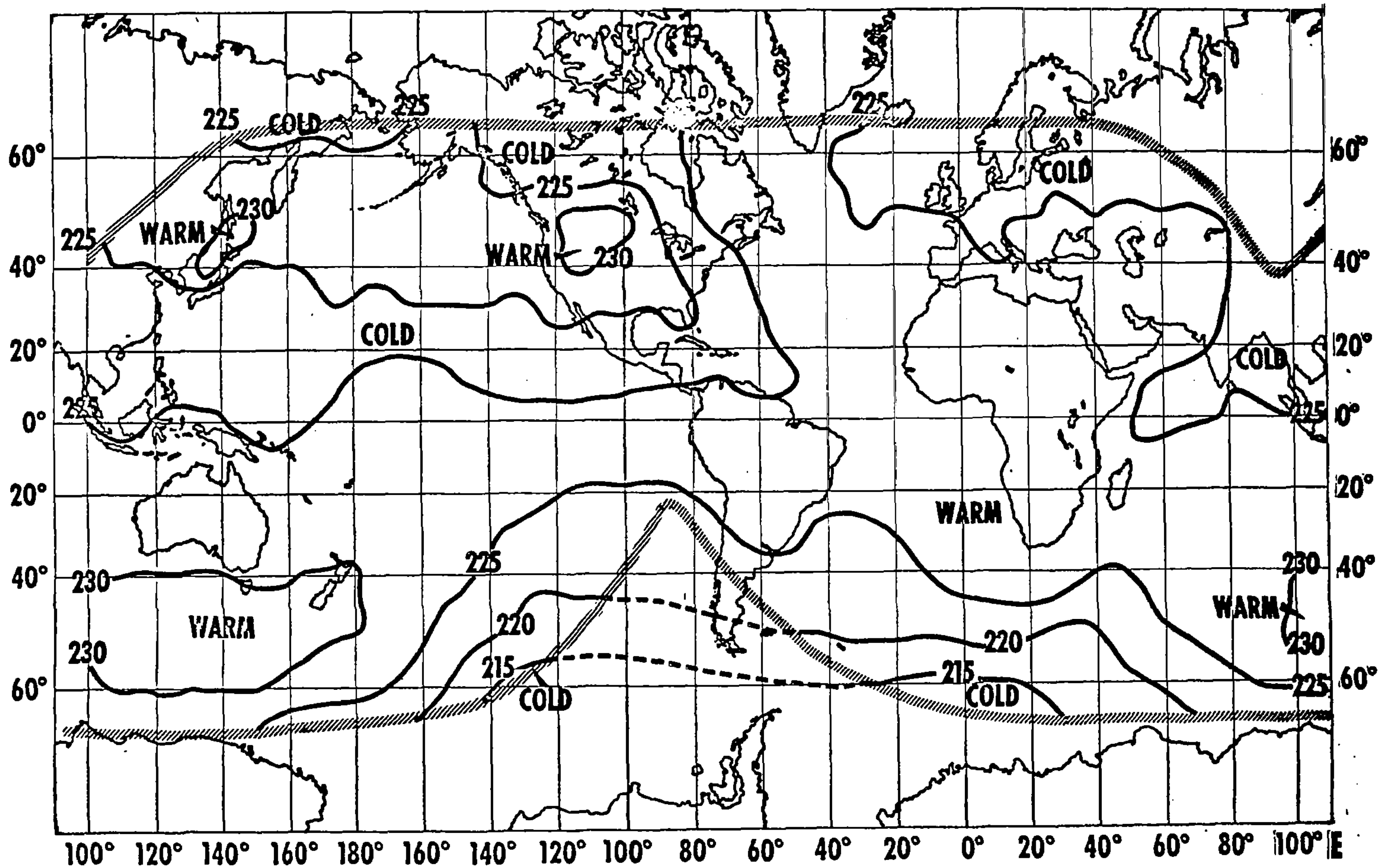


Figure 40. Tiros VII 15μ Isotherms, 11-18 September 1963
[From Ref. 97]

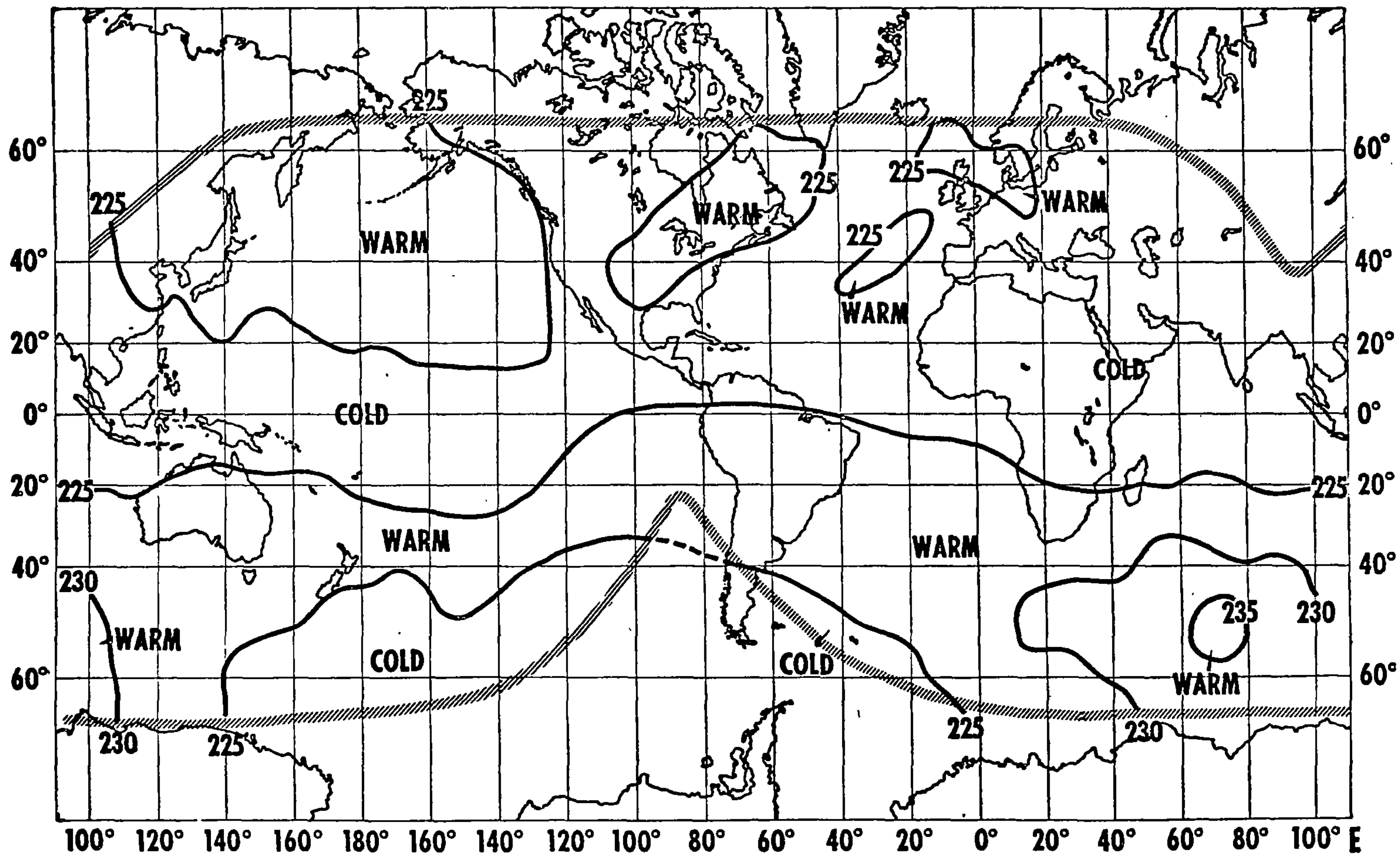


Figure 41. Tiros VII 15μ Isotherms, 25 September - 1 October 1963
[From Ref. 97]

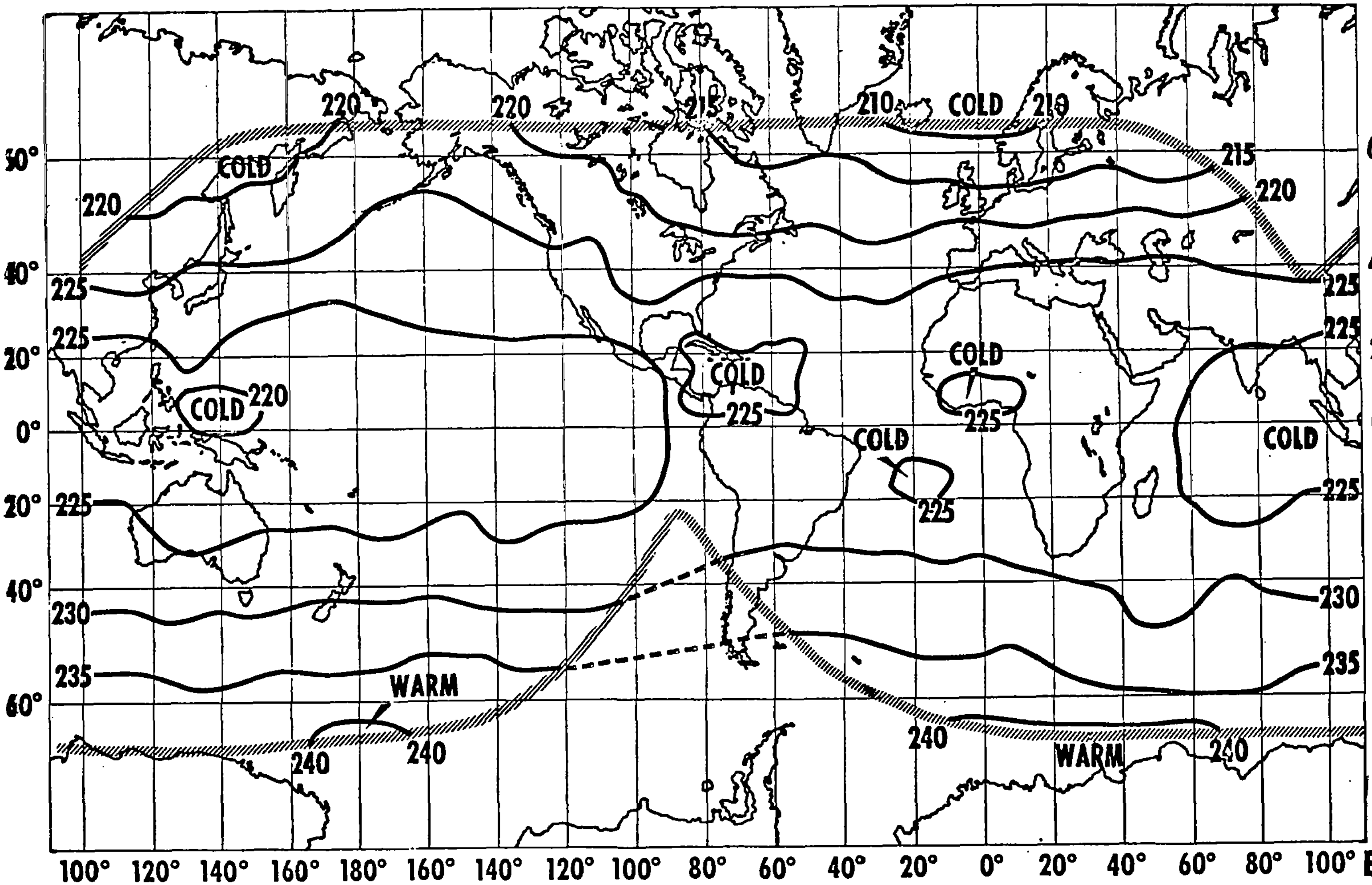


Figure 42. Tiros VII 15μ Isotherms 20-26 November 1963
[From Ref. 97]

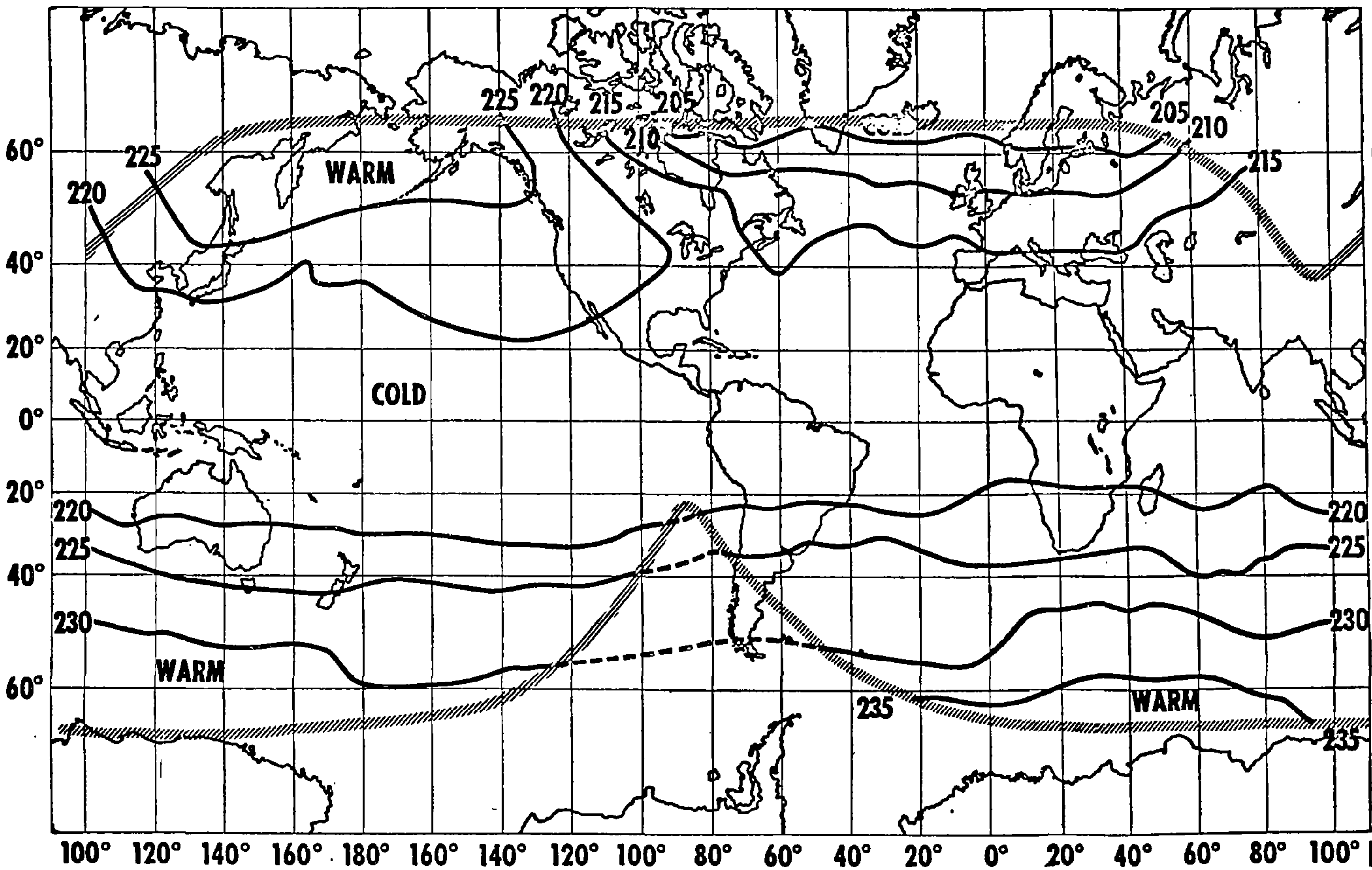


Figure 43. Tiros VII 15μ Isotherms, 15-22 January 1964
[From Ref. 97]

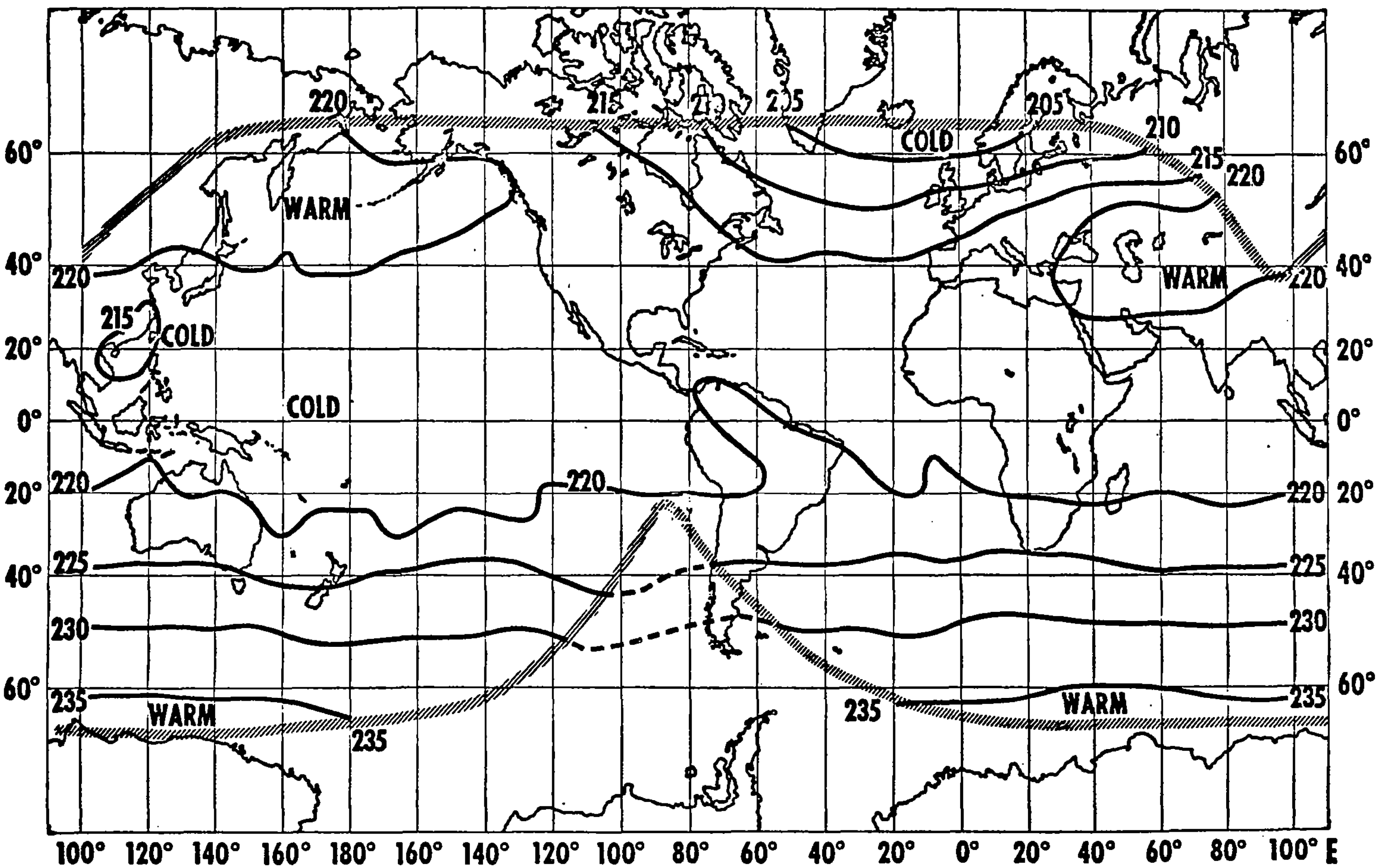


Figure 44. Tiros VII 15μ Isotherms, 22-29 January 1964
[From Ref. 97]

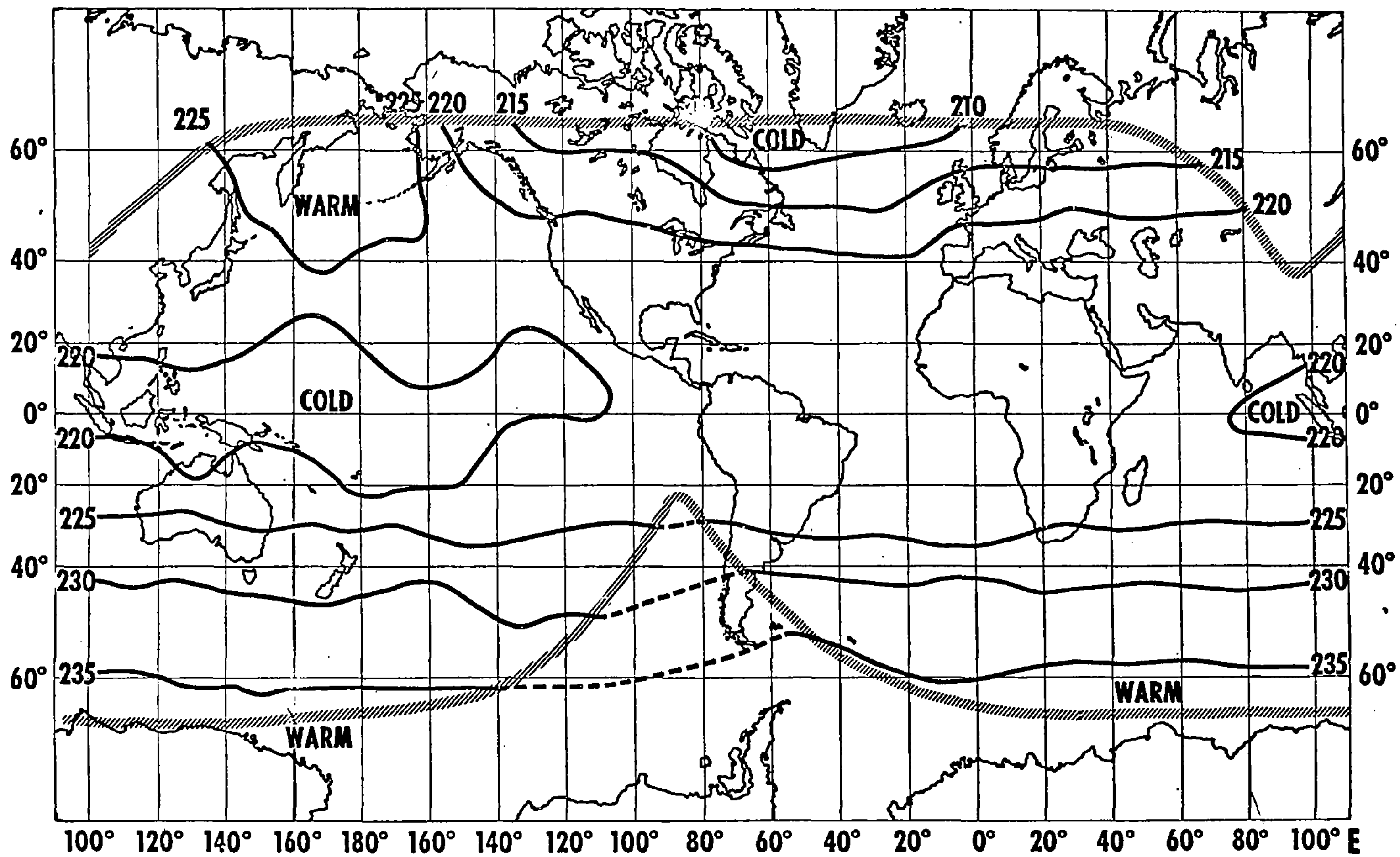


Figure 45. Tiros VII 15μ Isotherms, 31 January - 8 February 1964
[From Ref. 97]

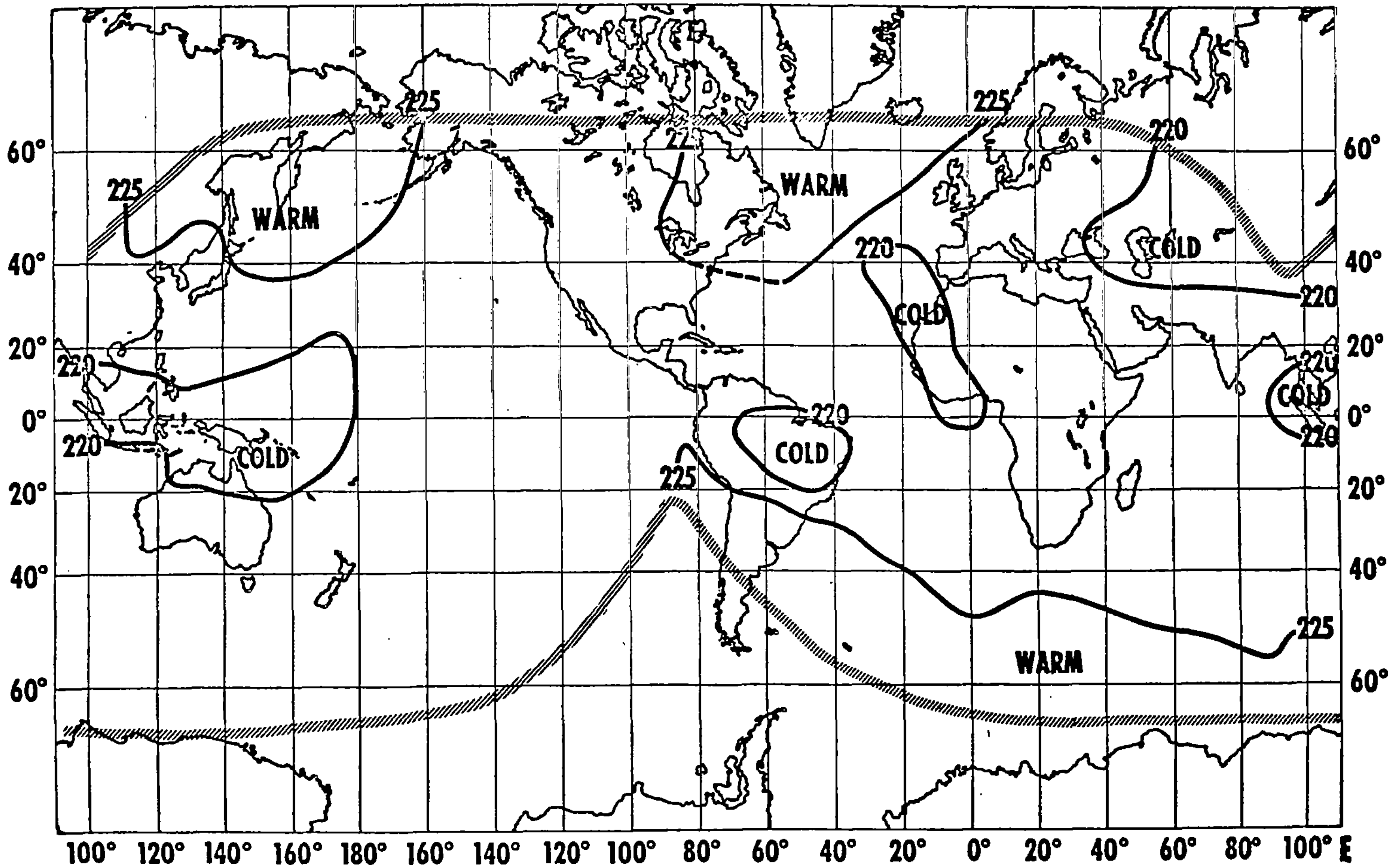


Figure 46. Tiros VII 15μ Isotherms, 18-25 March 1964
[From Ref. 97]

Because of the relatively high error associated with individual readings, considerable averaging is required to extract useful information from the data. Short term effects, such as diurnal variations, thunderstorms, etc. cannot be analyzed in good detail.

Bandeen, Conrath, and Hanel (ref. 98) showed oscillograms of individual scans of the Tiros VII radiometer which compared the outputs of the channels. These are reproduced in Figures 47 and 48. The line of sight was the same for all channels, thus, comparison of effects on the channels can be easily made. It can be seen from the data that noise and resolution tend to limit any deductions on horizon effects in the 15μ band. Within the noise level, no effects of clouds can be seen on individual scans in the 15μ channel in Figure 47. From the temperatures given for the 8 to 12μ channel the clouds must have been above 10 km. Several attempts were made to correlate the 15μ CO_2 channel with the 8 to 12μ window channel for a number of locations and times to determine cloud effects in the 15μ channel.[a] No correlation was obtained; thus, the conclusion was that cloud effects were below the noise level for this experiment.

Nordberg, et al., at GSFC have done considerable analysis on long term variations appearing in the 15 μ data from Tiros VII (ref. 97). The Earth's area sampled by Tiros VII was divided into a grid with cells of approximately 500 x 500 km dimensions. The measurements in each cell were averaged for one week (approximately 1000 measurements) to determine the average temperature of that cell. Isotherm maps were then drawn for the quasi-globe sampled by Tiros VII for several weeks from June 1963 to March 1964. Several of these maps are reproduced here in Figures 39 through 46. With this averaging out of random fluctuations, the precision of each temperature measurement is better than 1°K; however, systematic errors due to instrument degradation make the absolute accuracy considerably poorer than 1°K. The series of maps show seasonal variations and the general gradients in temperature as a function of latitude and longitude. Good descriptions of the seasonal or latitude gradients, the Aleutian Anticyclone effect, and an observed stratospheric sudden warming are given by Nordberg, et al., (ref. 97).

Since the preceding report was published, complete maps, drawn with higher resolution, more accuracy, and degradation corrections using 10-day averages at five-day intervals, have been made up for the Tiros VII 15μ band for its useful lifetime from June 1963 to October 1964. In private communications with W. Bandeen and J. Kennedy, four of the maps for July 1963; Sept. 1963; Jan. 1964; and March 1964 were obtained and are printed here in Figures 49 through 52. Summer hemisphere (Figures 49 and 51) isotherms run uniformly independently of longitude and have been noted to do so in all of the maps drawn. Temperature gradients as a function of latitude are very small at all times of the year in the region ±20° about the equator. Temperature gradients at the peak in the summer hemisphere from 20° latitude to 60° latitude

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[a] Private communication from W. Bandeen and J. Kennedy, Goddard Space Flight Center, Greenbelt, Maryland.

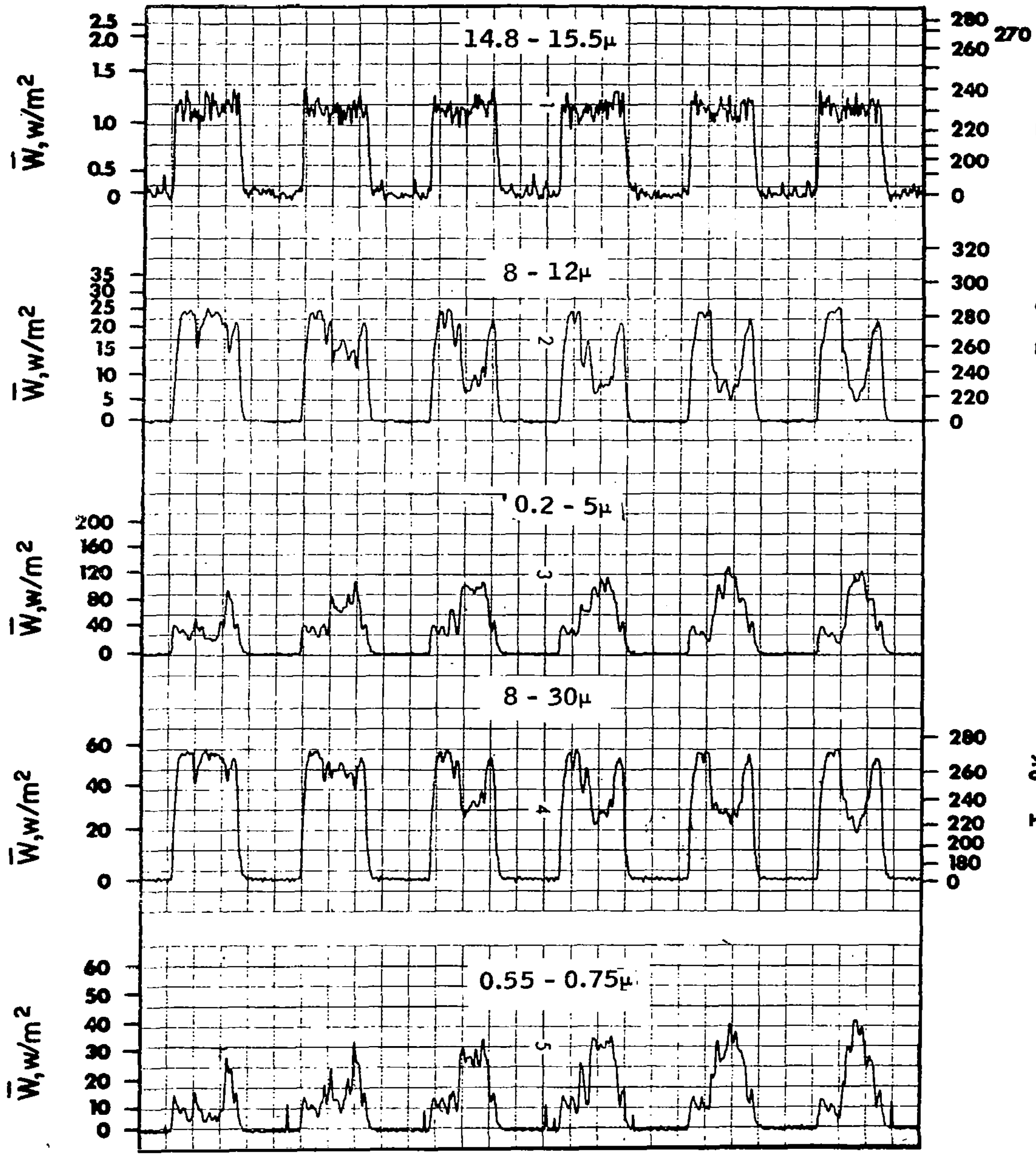

Figure 47. Cloud Effects Oscillogram Showing Six Scans Off the East Coast of Africa by the Tiros VII Radiometer [From Ref. 98]

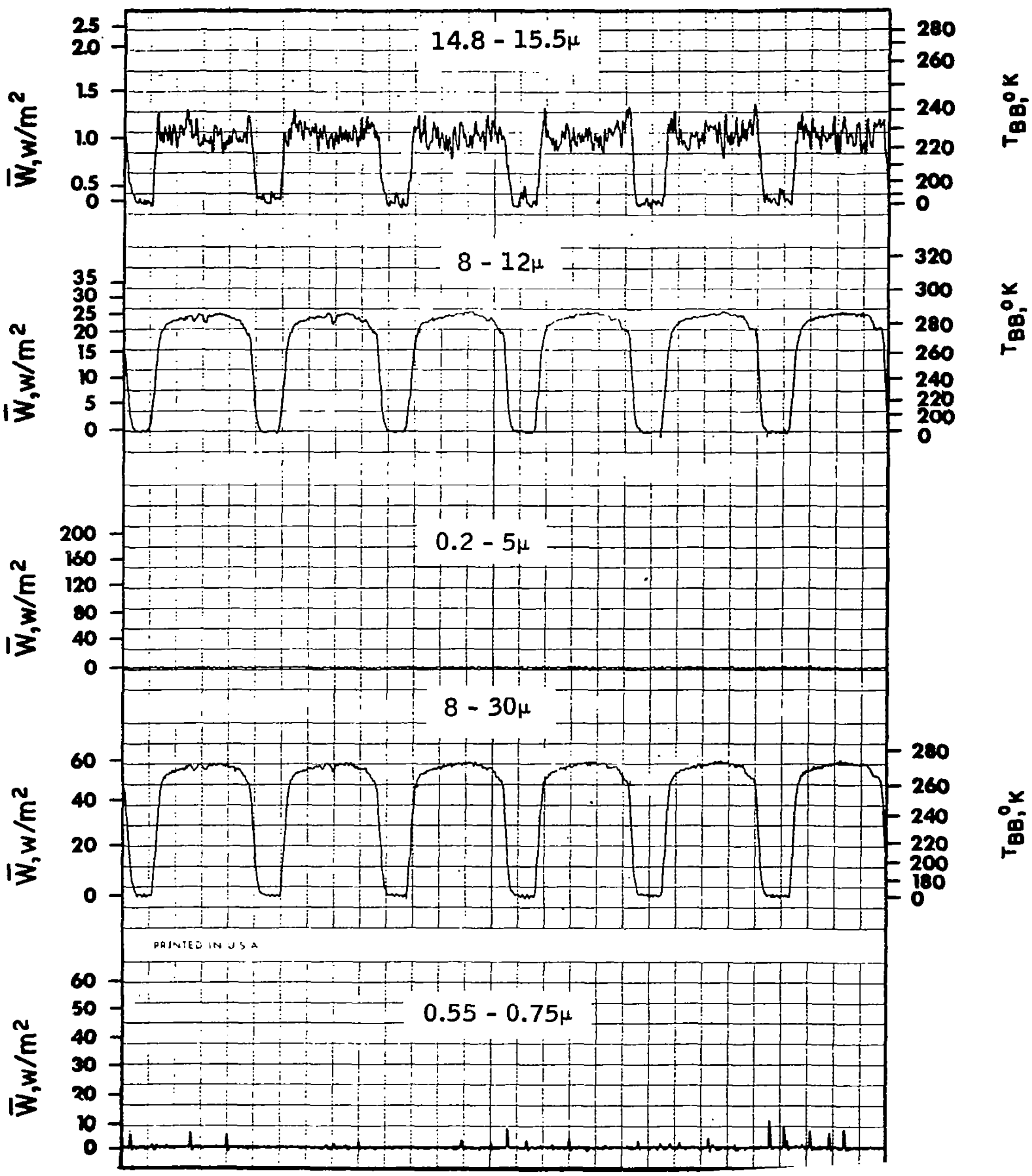

Figure 48. Limb Effects Oscillogram Showin Six Scans Over the Tropical Pacific Ocean at Night by the Tiros VII Radiometer

[From Ref. 98]

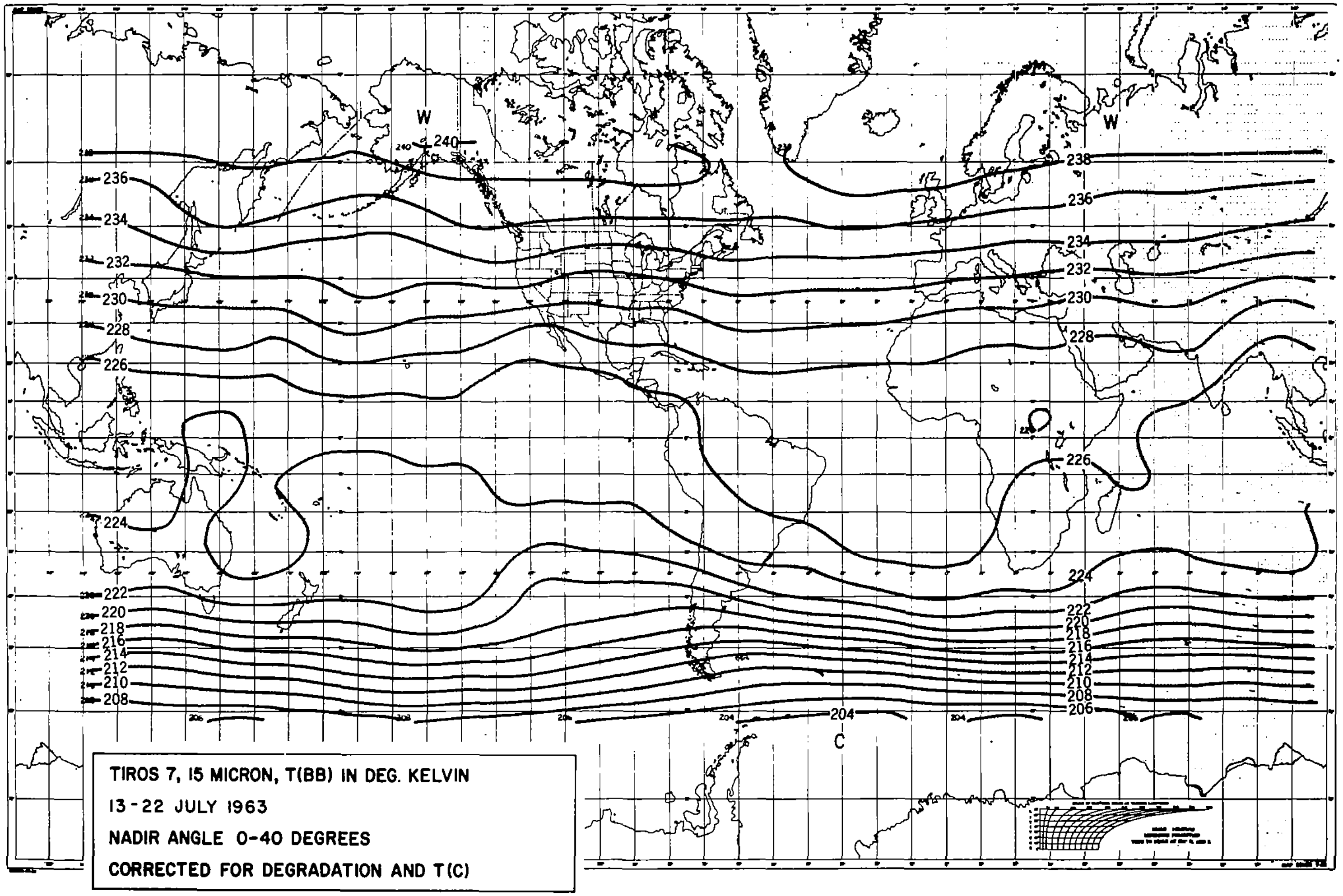

Figure 49. Tiros VII 15μ Isotherms, Corrected for Degradation, 13-22 July 1963

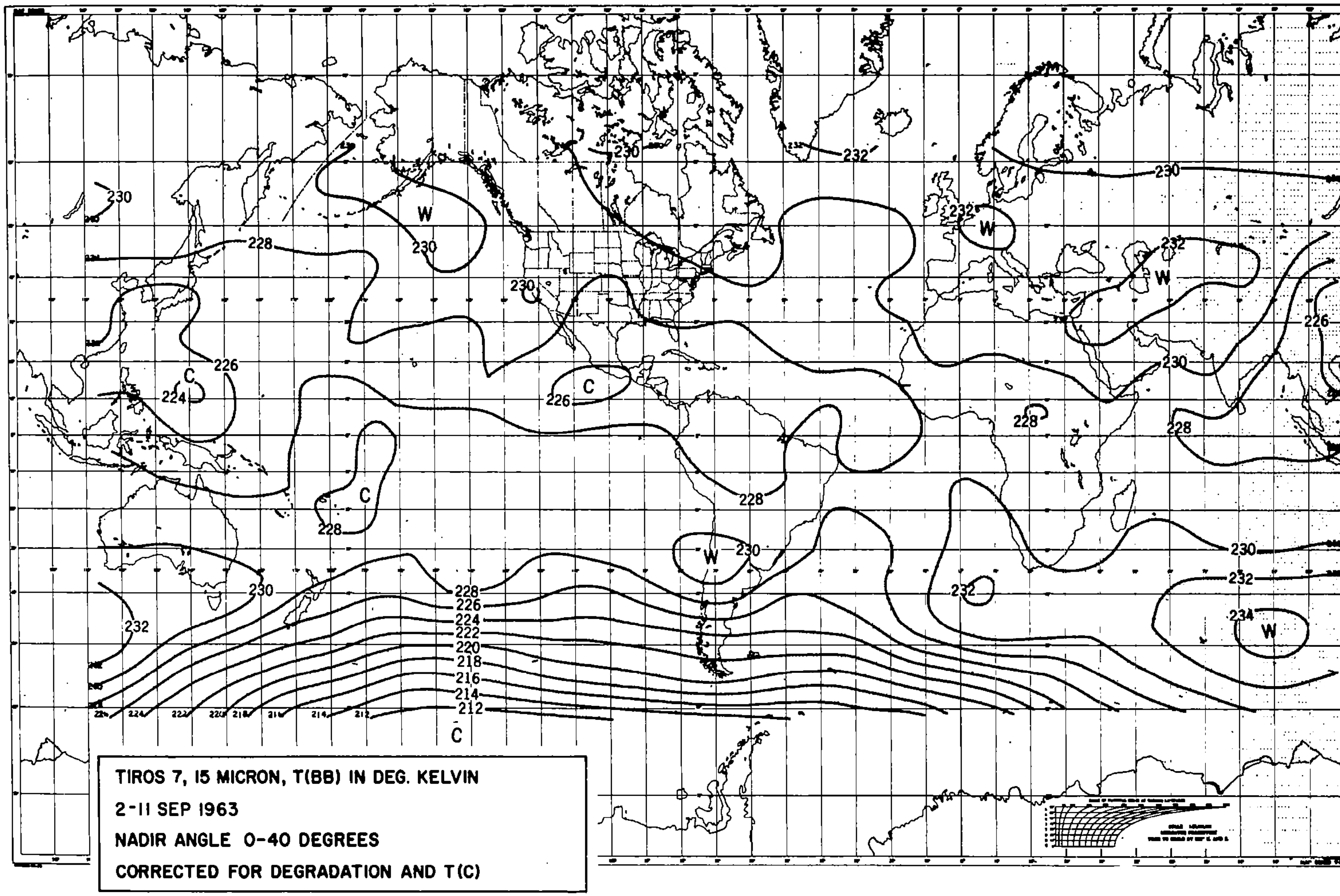

Figure 50. Tiros VII 15μ Isotherms, Corrected for Degradation, 2-11 September 1963

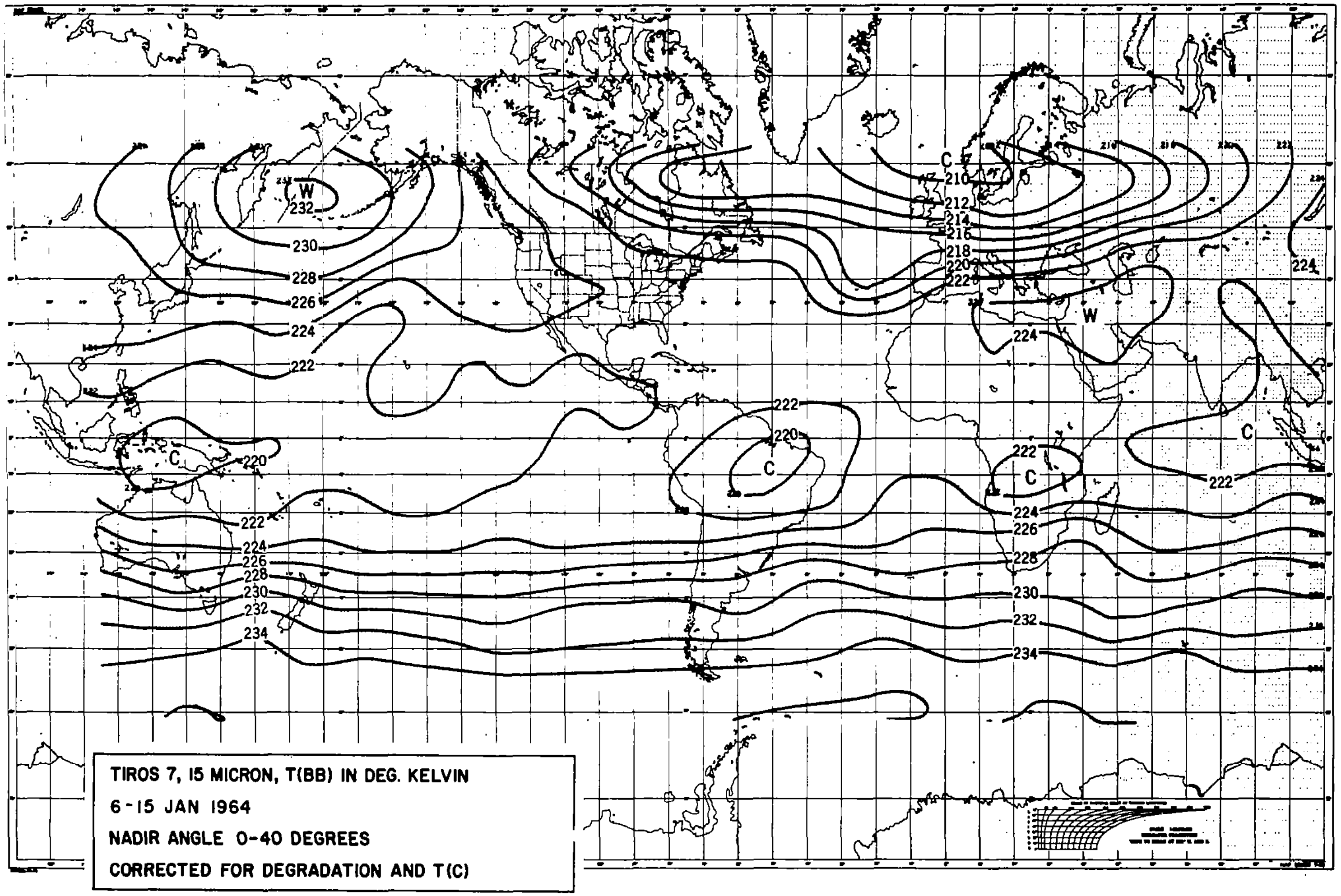

Figure 51. Tiros VII 15μ Isotherms, Corrected for Degradation, 6-15 January 1964

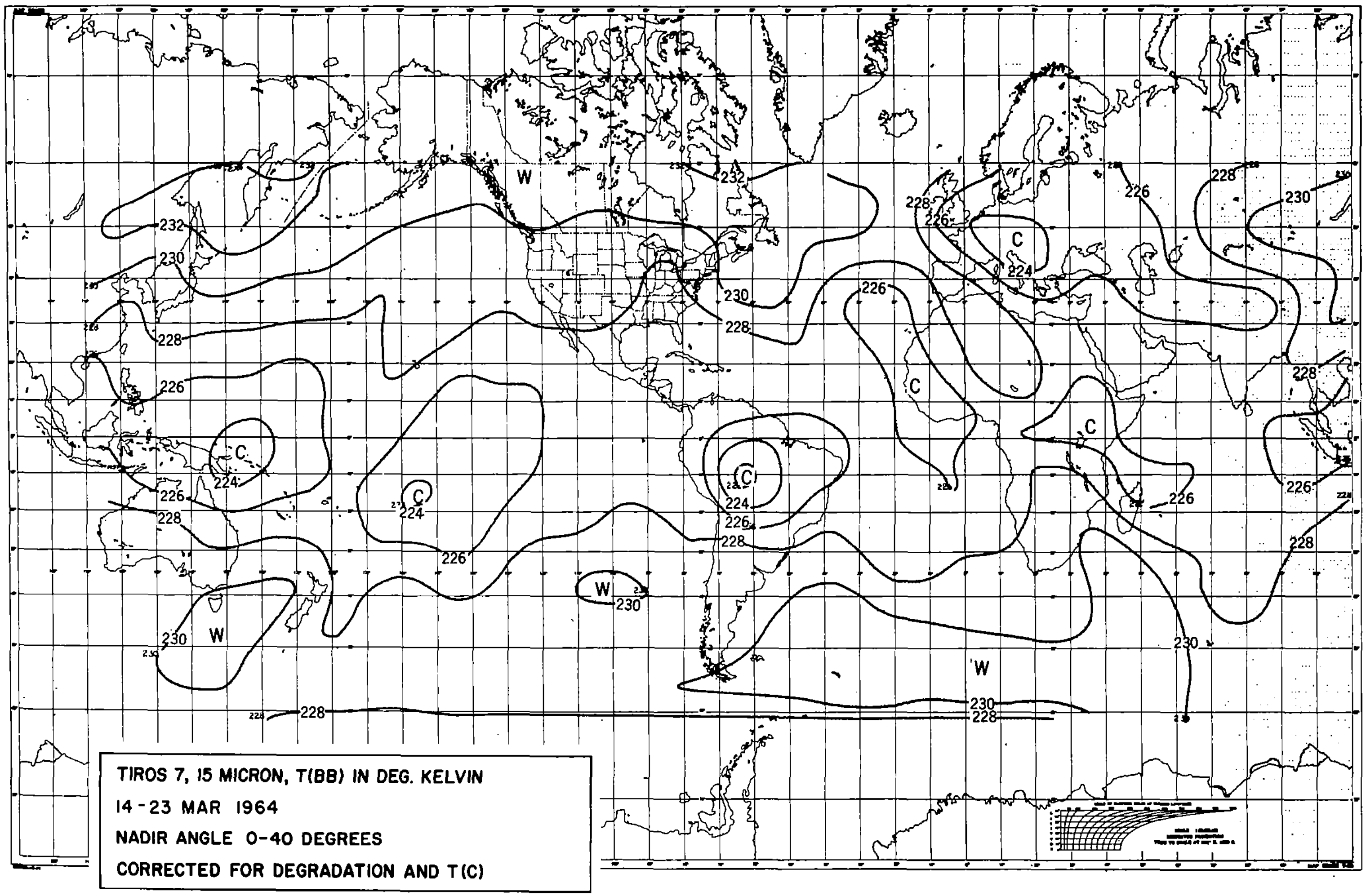

Figure 52. Tiros VII 15μ Isotherms, Corrected for Degradation, 14-23 March 1964

is approximately 1.4°K per 10° latitude. Temperature gradients in spring and fall (Figures 50 and 52) are very small and appear to be quite random. Isotherms in the Northern Hemisphere winter (Figure 51) are strongly influenced by the warm Aleutian Anticyclone. Indications are that the Aleutian Anticyclone occurs almost every winter, but its intensity and exact location varies considerably, which causes the isotherm shapes and positions to be quite unpredictable. The Southern Hemisphere winter shown in Figure 49 has better uniformity of isotherms than the Northern Hemisphere winter. However, in examining all of the maps, it is noted that a warm region over the Southeastern Indian Ocean acted similarly to the Aleutian Anticyclone and tended to distort the isotherms away from latitude lines throughout the winter. From the maps, it appears that summer long term temperatures (radiance) are predictable by latitude primarily. Long term temperatures for winter are not as predictable since relatively short term events such as movements of the Aleutian Anticyclone and stratospheric sudden warmings can cause large shifts in the isotherm patterns. Some geographical features, such as cooler areas over the Amazon Valley and warmer areas over the Sahara Desert, tend to appear through the averaging. More observations will be necessary for verification if the gradients and variations observed during 1963-1964 repeat, as well as how they repeat.

Some analysis on short term variations in the Tiros VII 15μ data was done by Aracon Geophysics Division of Allied Research Associates, Inc. (ref. 2). Spatial averaging over 2.5° by 2.5° areas on the Earth of data taken on the same orbit was used. Several examples are displayed showing that the 15μ channel averaged by this technique does show small cloud effects and short term weather patterns. Comparisons are made using conventional weather analysis and the Tiros VII 8 to 12μ channel. From the 8 to 12μ data, cloud top temperatures are determined. With the cloud top temperature and an atmospheric temperature profile, the cloud heights are approximated. For clouds filling the radiometer field of view, decreases in temperature of 1 to 4 °K should occur for clouds at 8 to 12 km. Effects of this order of magnitude were observed in the data. Only relative temperature patterns can be attained in this manner. Absolute temperature errors are of the same order as these variations.

LRC X-15

As part of Langley Research Center's horizon definition program, the X-15 airplane is being used as a vehicle to carry radiometers to the required altitudes for making meaningful Earth horizon measurements. This system, while having very limited coverage and output, is fulfilling its objectives of providing high resolution and high spatial position accuracy measurements on the horizon profile in several spectral bands at low cost with re-useable hardware. General descriptions of the program and data are given by Jalink (refs. 99 and 100).

The horizon definition experiment is essentially a piggyback payload on the primary X-15 experimental program. Little choice is allowed in time of flight or area of coverage. Flights are always roughly in a line along a path from Great Salt Lake, Utah, to Edwards AFB, California. A B-52 carries the X-15 from Edwards AFB to approximately 2/3 of the way to Salt Lake City where it is launched and returns to Edwards. The radiometer looks directly out the tail of the plane and scans the horizon in back of the vehicle from approximately Great Salt Lake to close to Edwards AFB. Data is taken while the plane is in the parabolic part of its trajectory.

A maximum of 20 complete profiles are obtained on a specific flight. Altitude of the vehicle changes very little during the data taking sequence and varies from 50 to 75 km depending on the particular flight profile. The profiles in the spectral intervals here observed are essentially the same as would be seen by a satellite since more than 99.9 percent of the atmosphere is below 50 km.

Good weather analysis is available with each flight. In addition, a Milliken movie camera is mounted alongside the radiometer to take visual pictures of the horizon. With model atmospheres generated from this data, theoretical horizon profiles are computed and compared to the measured data. Unfortunately, for analyzing cloud effects on the horizon profiles, weather conditions have to be good in the plane's trajectory or the flight doesn't take place. Thus, in most cases, weather conditions are good (cloudless), although in some cases the horizon being scanned may have clouds.

High accuracy attitude data is supplied from a stable platform on the X-15 with position data supplied by ground tracking radar. A total system error analysis (ref. 99) indicates a tangent height accuracy for each measurement of ± 1.87 km. The field-of-view of the radiometer is $0.13° \times 0.13°$, which provides a resolution of approximately 2 km at the tangent point. The radiometer characteristics are given in Table 16. In a system of this type, both pre- and post-flight calibration checks can be made and were. The data shown have been corrected for calibration biases and known errors. Both space to earth and earth to space profiles are obtained with the scanning technique used. Differences in the profiles occur due to response characteristics of the bolometer and amplifiers. Only space to Earth profiles are used, and these have been corrected for the response time errors.

A total of four flights have been made with this system. The first flight was made July 8, 1964, using a 0.8 to 2.8 μ filter on the radiometer. The boundary of all data taken, the average of all data, a typical measured curve, and the theoretical curve are shown on the graph in Figure 53. Cirrus and altocumulus clouds at altitudes up to 10 km appeared clearly on the radiometer data. The observing altitude for this flight was 52 km. Reasons for the deviations from the theoretical curve are explained by Jalink (ref. 99). The radiance values shown on the curves here and in the reference have not been corrected for filter and detector responses. To obtain absolute radiance values, these must be included.

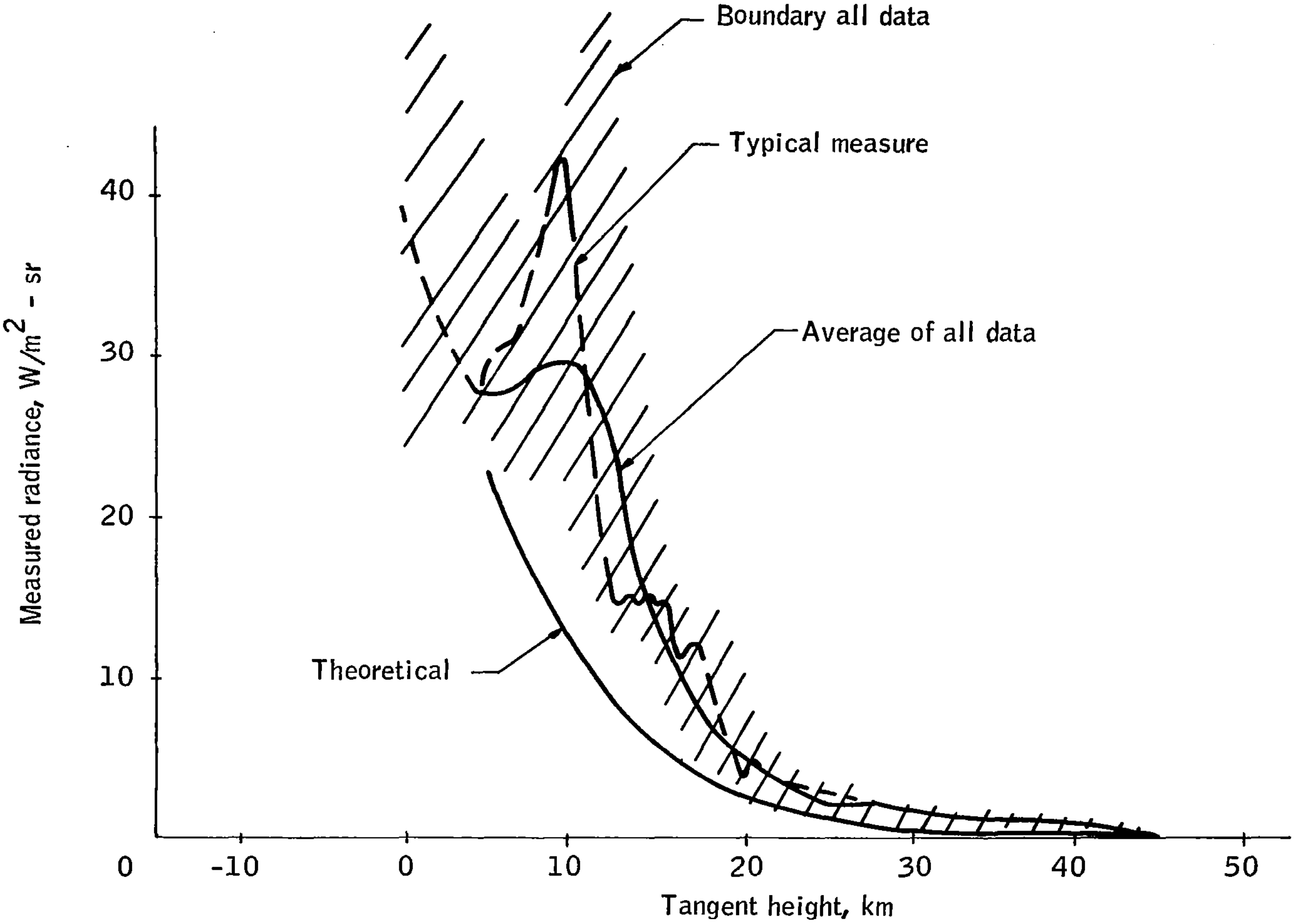

Figure 53. LRC X-15 Experiment 0.8 to 2.8 Micron Horizon Profile

TABLE 16. - X-15 RADIOMETER CHARACTERISTICS

Spectral region	0.8μ to 2.8μ	10μ to 14μ	14μ to 20μ
Aperture	12.7 cm	12.7 cm	12.7 cm
Focal length	12.7 cm	12.7 cm	12.7 cm
Field of view	0.13° by 0.13°	0.13° by 0.13°	0.13° by 0.13°
Scan angle	30°	30°	30°
Filter	Color filter 3 mm	Interference and absorption	Interference and absorption
Detector	PbS 0.3 mm by 0.3 mm	Thermistor bolometer 0.3 mm by 0.3 mm	Thermistor bolometer 0.3 mm by 0.3 mm
N.E.P.	2.4×10^{-1} watt-(cps)$^{-1/2}$	3.4×10^{-8} watt-(cps)$^{-1/2}$	2.5×10^{-8} watt-(cps)$^{-1/2}$
Time constant	3.5×10^{-3} sec	3.5×10^{-3} sec	3.1×10^{-3} sec

The second flight was made in May, 1965, using a 10 to 14 μ filter on the radiometer. The data were taken on a very clear day and the radiance profiles were correspondingly very smooth as shown in Figure 54. This region is primarily a window region as can be seen by the low altitude at which the steep part of the profile occurs. If clouds had been present in the field of view, they would have had a major effect on the profile shapes.

The third flight was made June 29, 1965 using a 14 to 20 μ filter on the radiometer. The detector and optical filter response curves are shown in Figures 55 and 56, respectively. The altitude at data taking was approximately 75 km. A total of eight profiles were obtained on this flight and are shown in Figure 57. Profiles for this spectral region show an interesting double horizon. Above 20 km, the radiance is predominantly due to CO_2 emitting in the 14 to 16 μ region. The second horizon centered at approximately 10 km is due to water vapor emission in the 16 to 20 μ region. The boundary of all data, average of all data, and the theoretical curve are shown in Figure 58. Considering that the tangent height accuracy of the system is ±3.7 km (2σ), the profiles show a high degree of stability. The weather during this flight was essentially cloudless. Terrain varied from high desert to mountains to low desert. The experimental profiles fit the theoretical curve very well in the CO_2 region. An unexplained discrepancy occurs in the water vapor region.

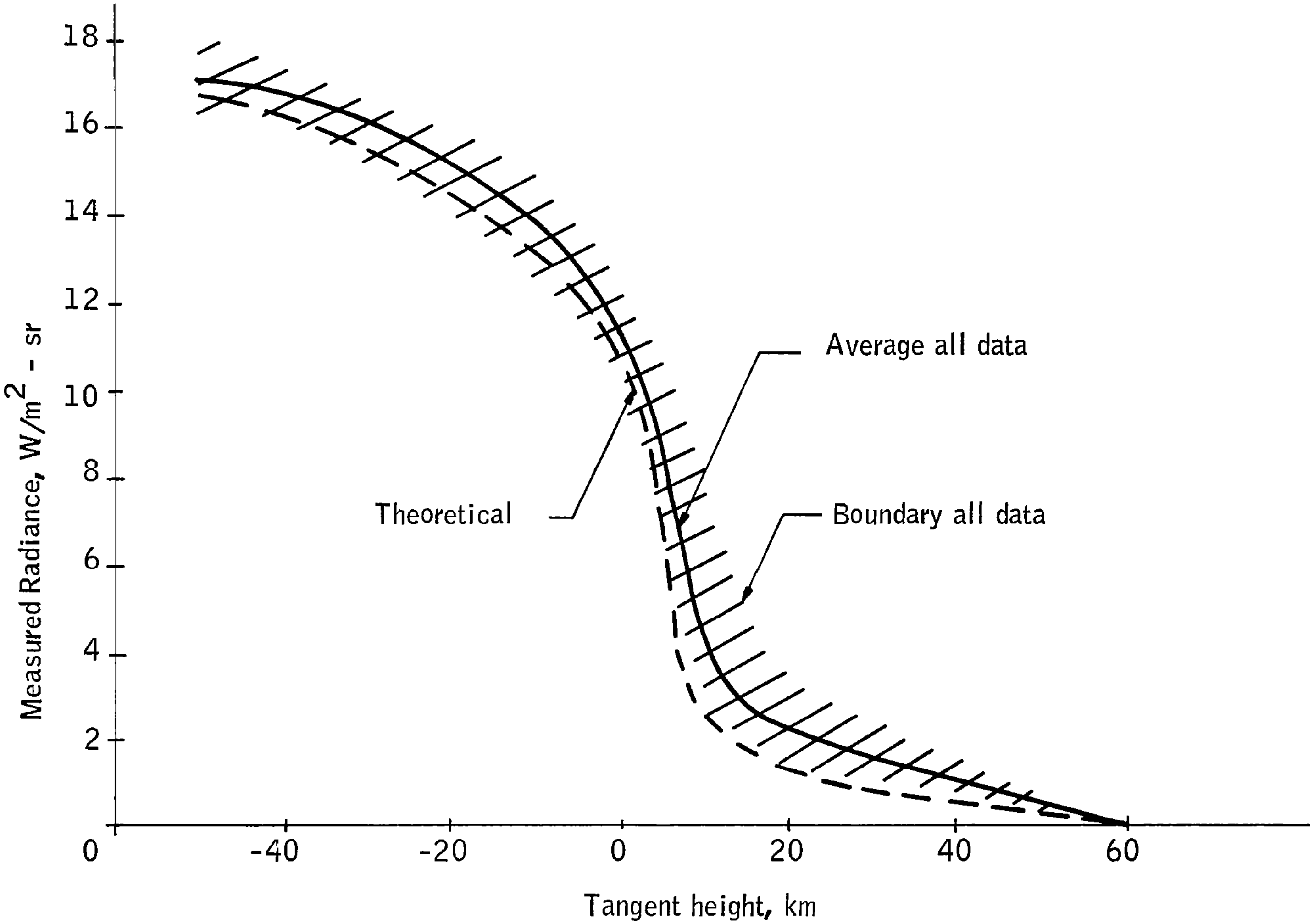

Figure 54. LRC X-15 Experiment 10 to 14 Micron Horizon Profile

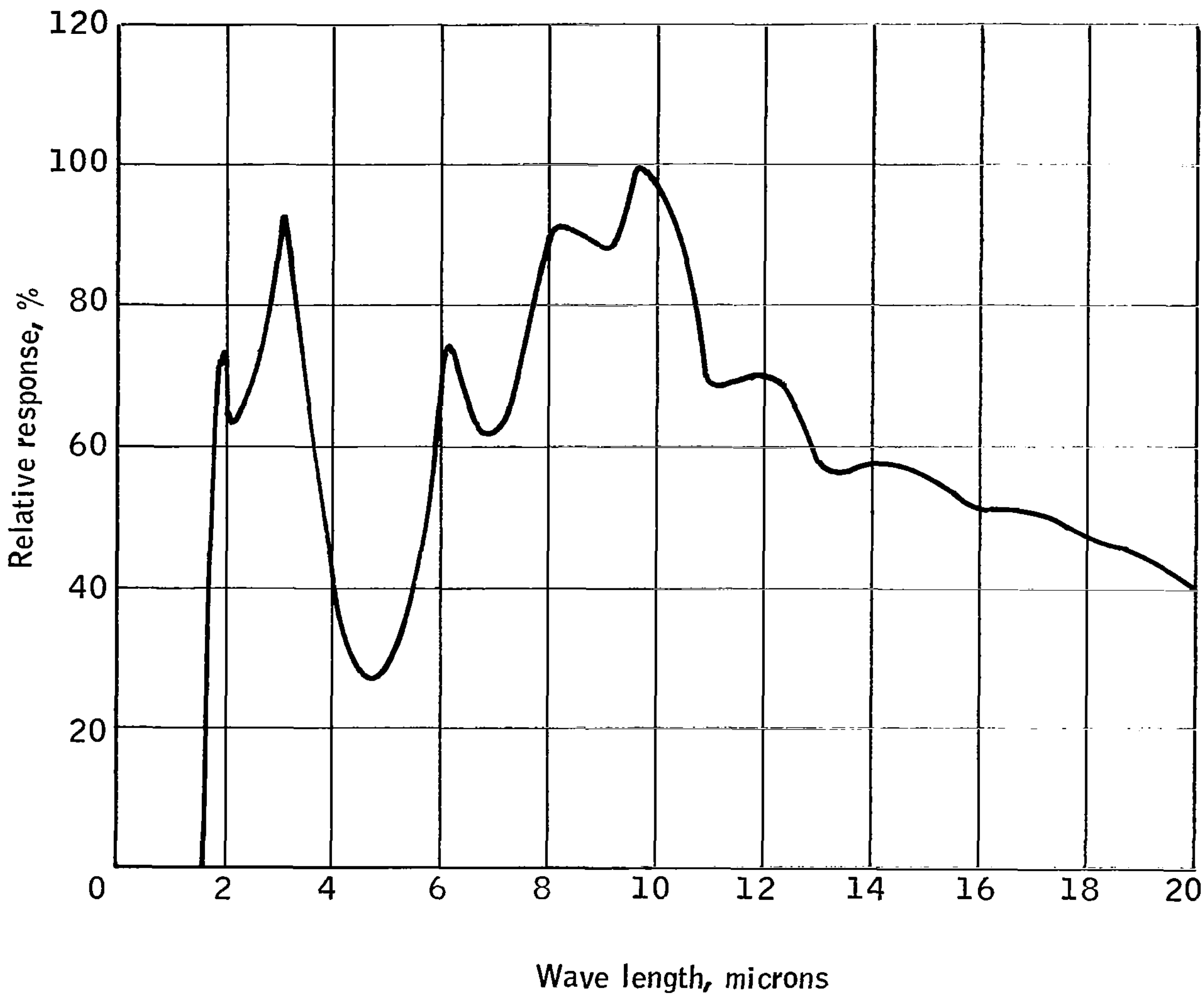

Figure 55. LRC X-15 Experiment For Infrared Radiometer Detector Response
[From Ref. 99]

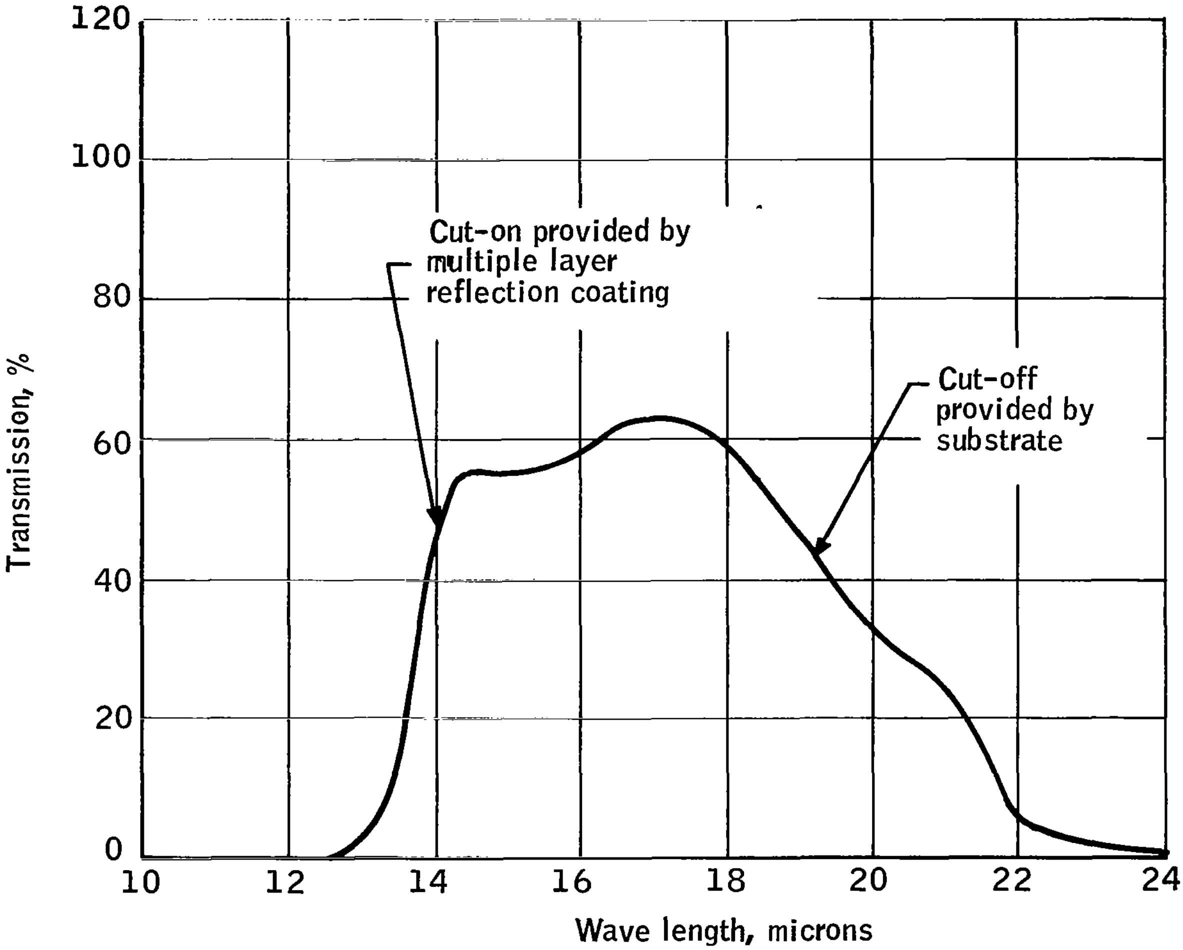

Figure 56. LRC X-15 Experiment Optical Filter 14 to 20 Microns [From Ref. 99]

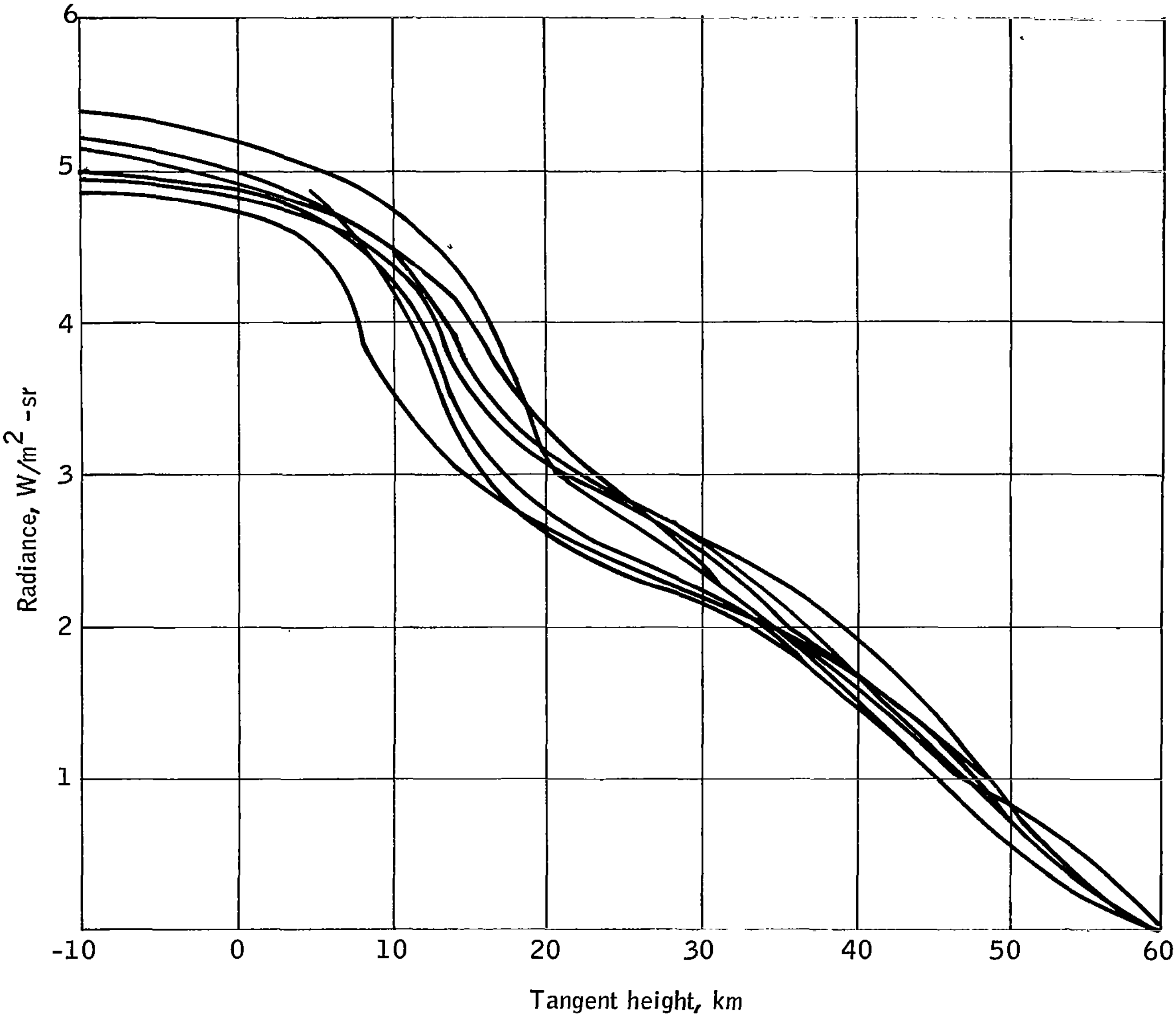

Figure 57. LRC X-15 Experiment 14 to 20 Micron Horizon Profiles

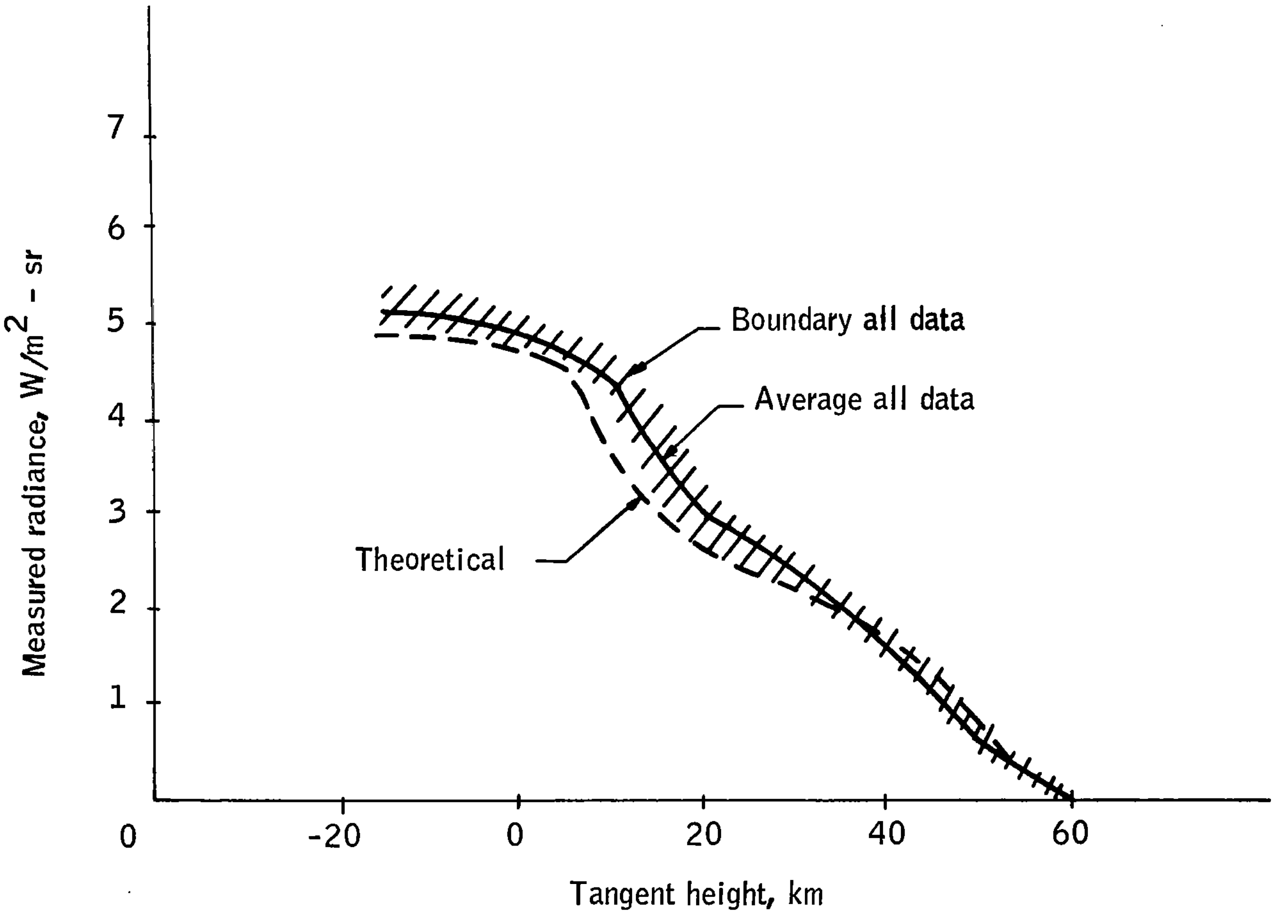

Figure 58. LRC X-15 Experiment 14 to 20 Micron Horizon Profiles

A fourth flight made in October, 1965, also covered the 14 to 20 μ region. Due to difficulties on the plane, attitude could not be determined and no data resulted. Plans call for making further measurements in the 14 to 20 μ spectral region on following flights.

NIMBUS II

The Nimbus II weather satellite was launched into polar orbit with an angle of inclination of approximately 100° on May 15, 1966. At the date of this writing, the system is still functioning normally. The Nimbus outputs consist of television pictures of cloud cover in the visible region, high resolution infrared radiometer (MRIR) pictures of radiation in five spectral intervals of the infrared region. Two channels of the MRIR are of particular interest in horizon definition analysis of the 14 to 16 μ band. From the 10 - 11 μ window channel, cloud top temperatures and thus heights can be determined. The 14 to 16 μ channel provides direct measurements of temperature in the CO_2 band.

Goddard Space Flight Center is responsible for spacecraft management, data collection, and analysis. The information on the Nimbus system and the data presented here were obtained in private correspondence with A. McCulloch and W. Bandeen of GSFC and A. Glaser of Aracon Geophysics Div. of Allied Research Associates, Inc.

The Numbus satellite is in a near circular polar orbit at an altitude of approximately 1100 km ± 40 km. The satellite is stabilized to local vertical to ±3° in roll and pitch and ±10° in yaw. The MRIR has a field-of-view of 2.3° at the 1/2-power point corresponding to an area of approximately 30-mile diameter vertically below on the ground. A rotating mirror scans the radiometer FOV across the diameter of the Earth's disk, through both horizons, and space at a rate of 1 scan per 7.5 sec. providing a ground resolution between scans of approximately 30 miles.

The effective spectral response of the CO_2 channel of the MRIR is shown in Figure 59. The 1/2-power points are approximately at 14.05 μ and 15.75 μ.

It should be noted that the response curve does not fall off uniformly above 15.75 μ. Apparently this skirt passes a significant quantity of energy from the water vapor band since more cloud effects are noted in the data than would be expected for the CO_2 band alone.

Nimbus MRIR data will be placed on Final Meteorological Radiation Tapes (FMRT) in a form similar to the FMRT's produced from Tiros VII. At the present time, the MRIR data is available in two forms, analog strip charts and pictorial presentations. The analog strip charts consist of a reproduction of the radiometer outputs in time sequence as shown in Figure 60. Horizons and disk readings are as marked in the figure. Distance on the Earth between

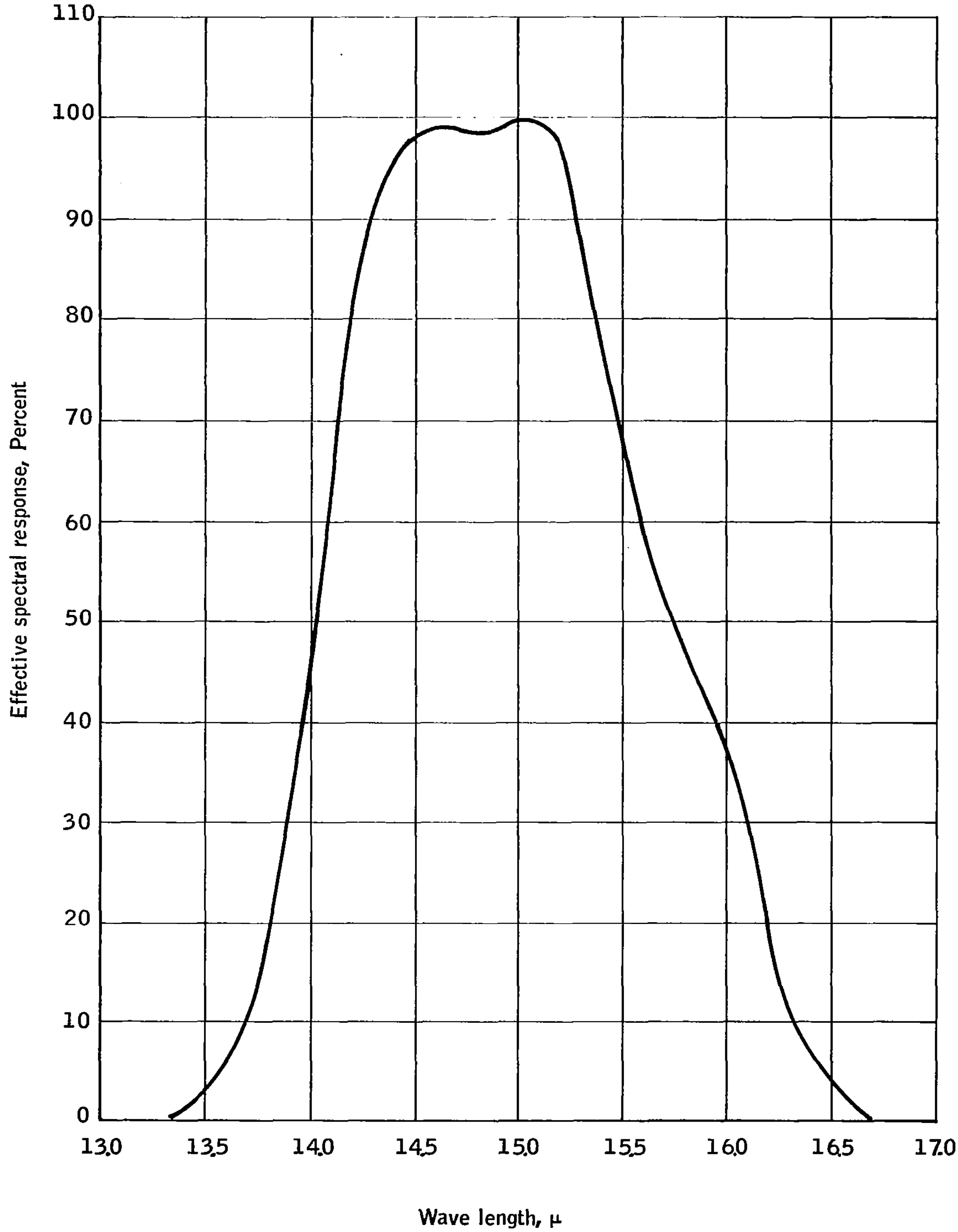

Figure 59. Effective Spectral Response of 14 to 16 Micron Channel MRIR Nimbus II

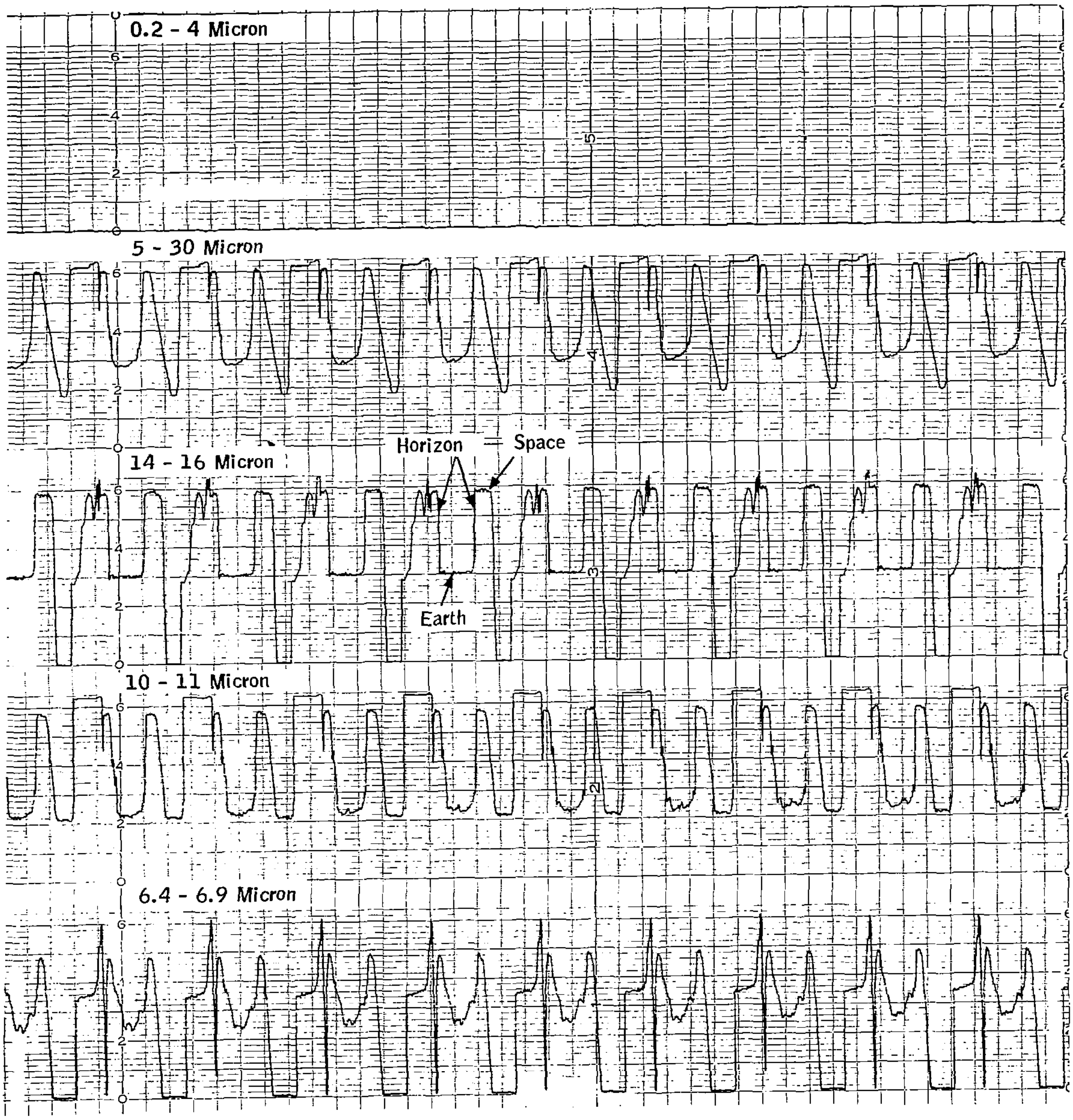

Figure 60. Reporduction of Nimbus II MRIR Outputs, Clear Sky

horizons is approximately 7200 km. Resolution (approximately 160 km at the horizon) and the high scan rate (48°/sec) make analysis of the shape of the horizon impossible with this data. The pictorial presentation is generated by stacking the analog scans to form a continuous strip picture of one orbit of data as shown in Figure 61. In this presentation, the horizons have been cut off and a 4600 km wide strip directly below the spacecraft is displayed. Cold is light and warm is dark on the figure for all channels except the 0.2 to 4.0 μ channel which measures primarily reflection rather than emission. The pictorial presentation is useful for determining the location of gross effects in the channels. Precision measurements of the amplitudes of the variations can then be made on the analog strip charts.

Unfortunately, problems with the radiometer at this time limit good data in the 14 to 16 μ band to latitudes north of approximately 60°S latitude. Apparently the geometry is such that over the South Pole sunlight is reflected into the radiometer, which causes heating and a loss of calibration. It may be possible to correct for this heat increase with careful analysis, but it has not been done for this report. As the geometrical relationship between sun, Earth, and satellite changes, this problem should clear up or shift in geographical location.

Many orbits of the Nimbus data have been examined. Clouds appear in the 14 - 16 μ channel at least to some extent, in every orbit in the intertropical convergence zone near the equator. This can be clearly seen in Figures 61 and 62. In May, this area occurs at approximately 10°N latitude. In general, the average temperature measured in this region is approximately 222°K. The clouds caused decreases in temperature normally of less than 10°K, although cases were noted of temperature decreases as high as 17°K. Clouds also occur in several other areas on almost every orbit but are more random and usually lower in amplitude.

Figure 63 shows the effect of clouds near the horizon in the 14 to 16 μ band. Approximately a 4 to 6°K decrease in temperature of the 14 to 16 μ band can be observed. Because of the larger area encompassed in the field of view, the clouds generally tend to average out and disappear near the horizon. Figures 64 and 65 show clouds nearly vertically below the spacecraft. The amplitudes of the variation in temperature of the 14 to 16μ band due to these clouds are approximately 10°K and 12°K, respectively. Both of these cases occured in the intertropical convergence zone. By reading the temperatures of the cloud tops in the 10 - 11 μ channel as 209°K and 193°K and comparing to a standard tropical atmosphere, the heights of the clouds are approximately 13 and 17 km, respectively. These figures are reproductions of expanded scale analog strip charts. To analyze cloud effects near the horizon, the strip chart recorder speed was increased to provide better resolution. The staircase effect on the horizon is a result of the digital sample rate on the magnetic tape recording from which the strip chart is made.

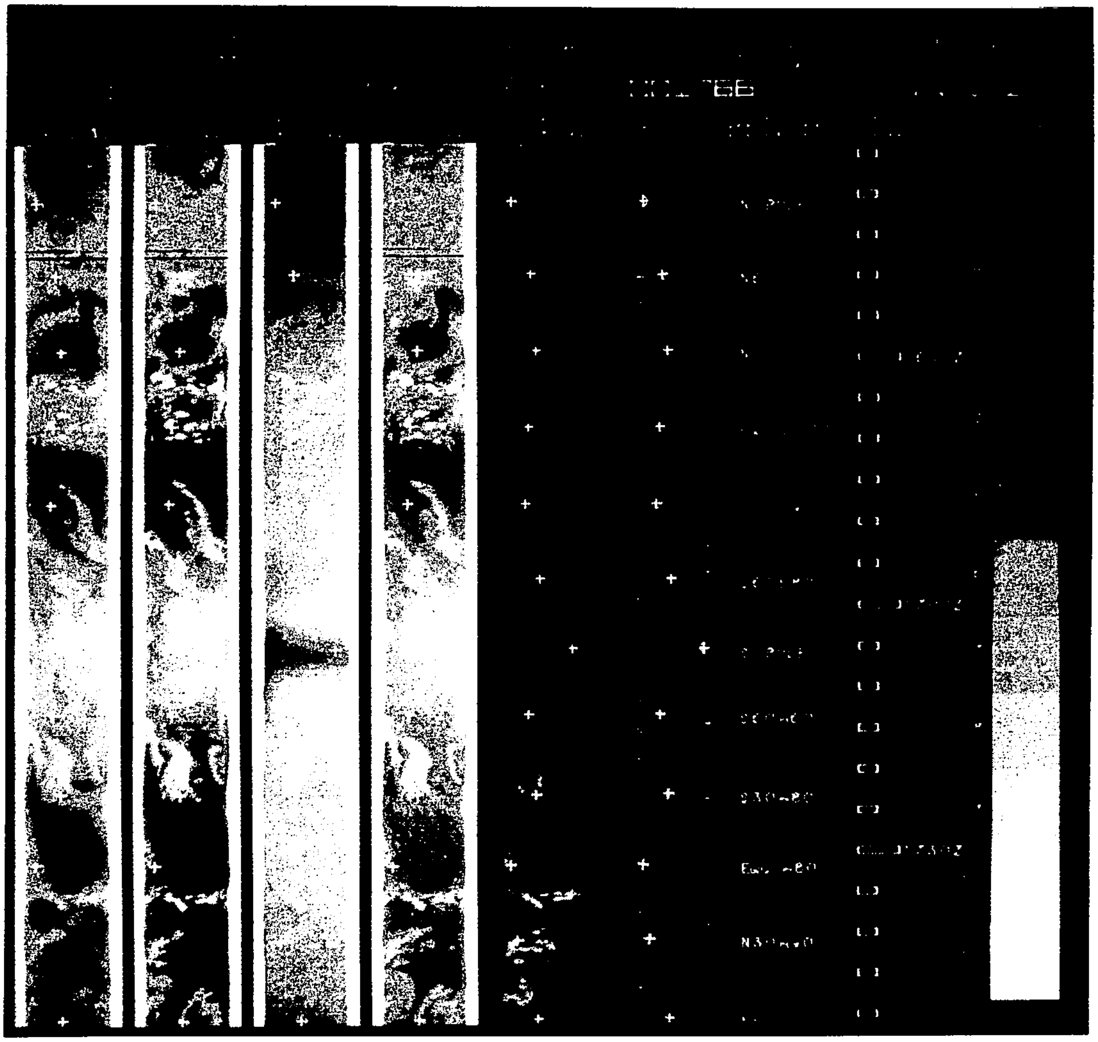

Figure 61. Pictorial Presentation Nimbus II MRIR Orbit 59

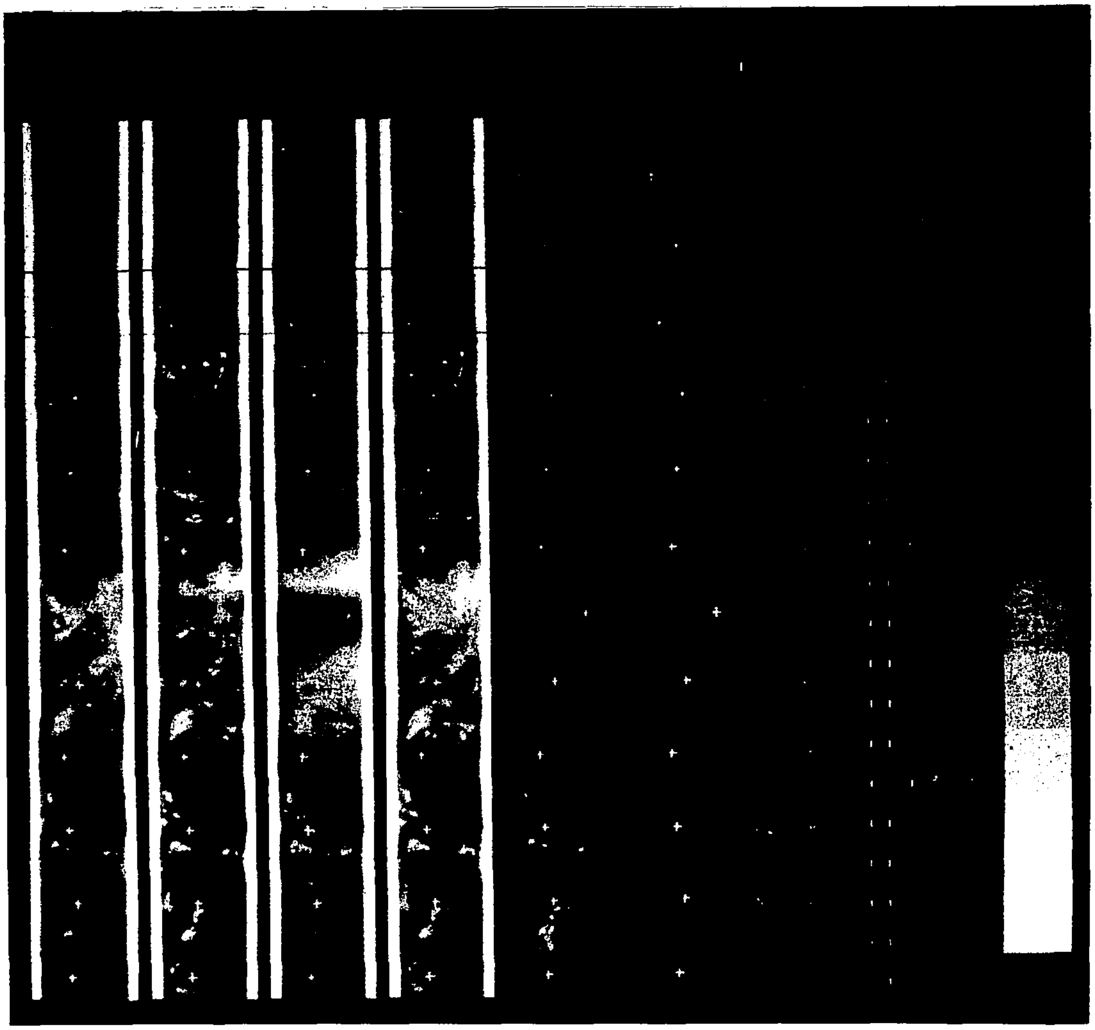

Figure 62. Pictorial Presentation Nimbus II MRIR Orbit 112

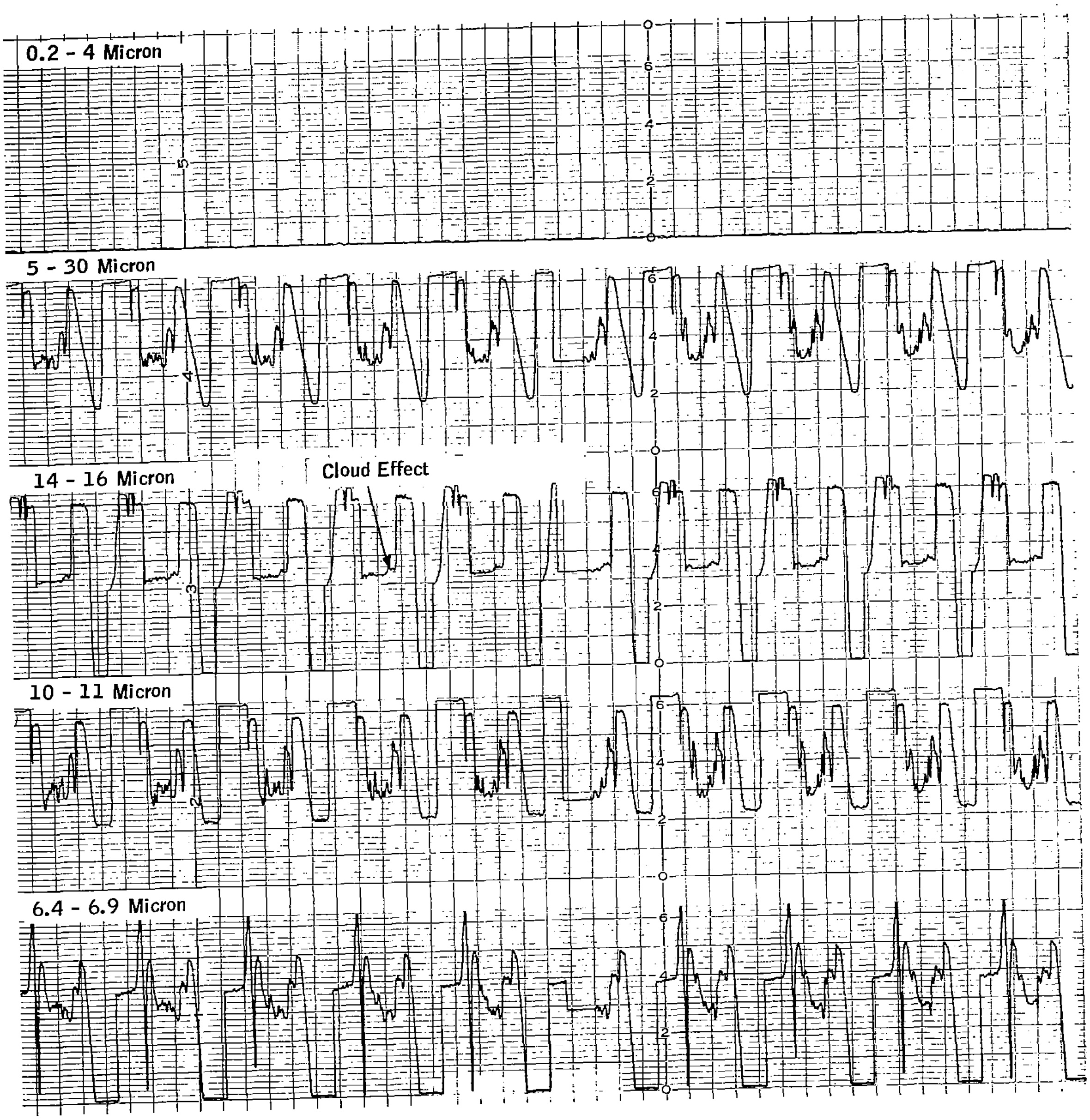

Figure 63. Nimbus II MRIR Outputs Showing Clouds Near the Horizon, Orbit No. 145, 26 May 1966

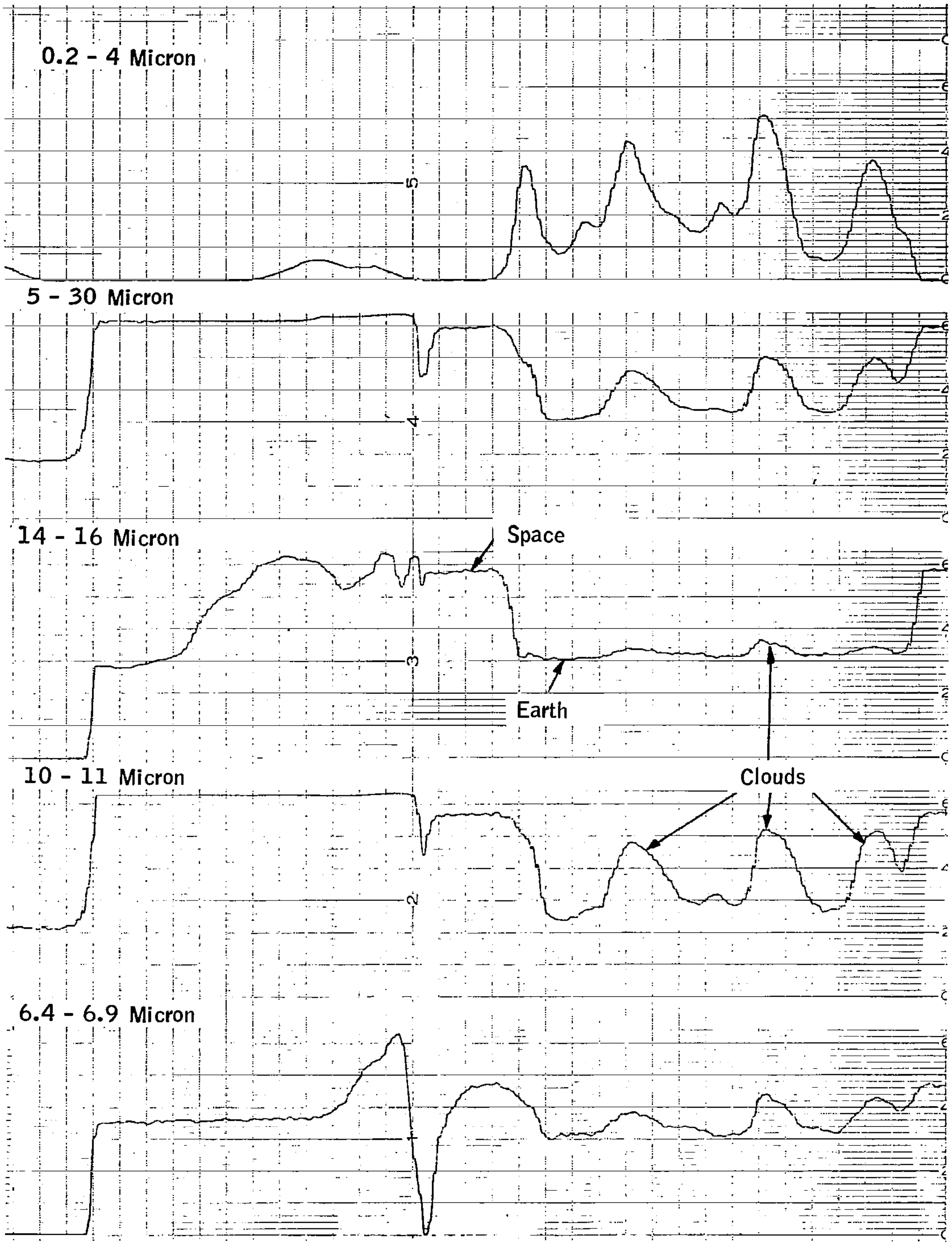

Figure 64. Nimbus II MRIR Outputs Expanded Strip Chart Showing Cloud Effects, Orbit No. 145, 26 May 1966

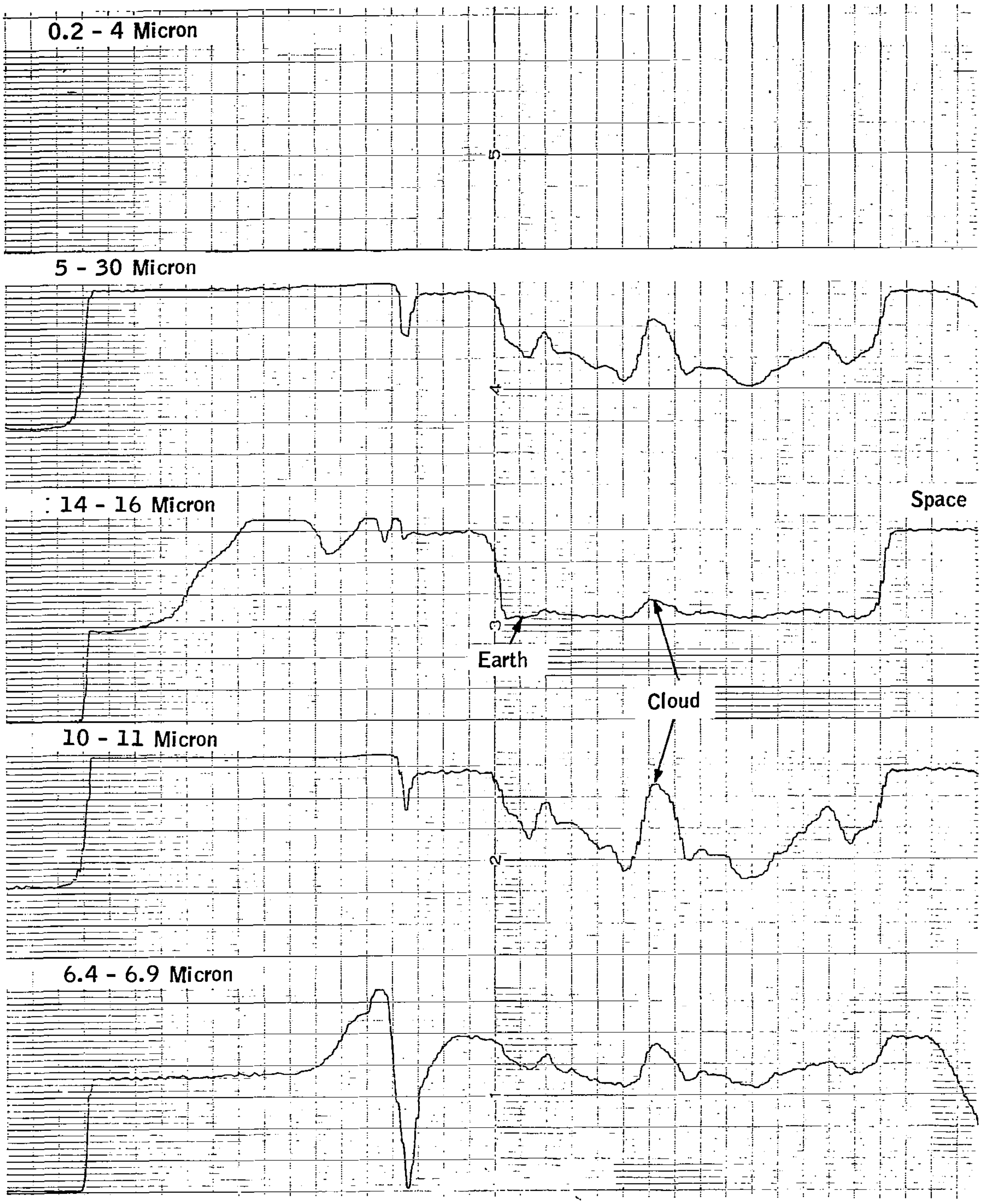

Figure 65. Nimbus II MRIR Outputs Expanded Strip Chart Showing Cloud Effects, Orbit No. 145, 26 May 1966

Plots of temperature in the 14 to 16 μ band as a function of latitude were made for three orbits and are shown in Figures 66, 67, and 68. Pictorial presentations of two of these orbits are shown in Figures 61 and 62. The three orbits span a time period of one week, 19 to 26 May. The curves show a very linear temperature increase of 10°K per 6.7° latitude from approximately 30° N lat to the North Pole. Deviations are less than ± 1°K from an average curve in this region. From 60° S lat to 20° S lat the same increase of 1°K, per 6.7° lat occurs, although the deviations are up to ± 25°K. A temperature plateau appears to exist in the region from 20° S. lat to 20° N lat. Deviations are ± 2.5°K. The temperatures plotted here are the average temperature of the radiometer scan across the Earth's disk of 7200 km. This averaging tends to remove effects of clouds, except possibly in the intertropical convergence zone, and geographical conditions such as land or water. Some indications of a diurnal temperature variation of 1 to 2°K higher in the day than at night shows up in the graphs, but it could not be completely verified from the limited data analyzed to date. Night is the dark area on the 0.2 to 4.0 μ channel on the pictorial presentations. For daytime measurements for a given latitude the temperature is quite consistently higher than the nighttime measurements.

The analysis of the Nimbus II MRIR data shown here is preliminary. The good resolution, high signal-to-noise ratio, and easy position determination of the data allows for simple analysis. With the data taken to date, diurnal, geographical, cloud, and other variations in the 14 to 16 μ channel could be analyzed statistically in good detail. If the lifetime of the vehicle is sufficient, seasonal temperature variations can be mapped in detail similar to the mappings made for Tiros VII. Although the measurements are made on the disk of the Earth, much of the variation analysis can be directly applied to horizon analysis. In addition, the Nimbus II, 10 to 11 μ channel provides data for determining cloud heights which may be used to correctly calculate horizon profiles for cloud effects. By reading the temperature of the cloud top from the 10 to 11 μ channel and comparing it to an atmospheric temperature profile, the cloud height can be determined. The cloud is then treated as a near black body radiating at that altitude in the profile computation.

PERIPHERAL EXPERIMENTAL PROGRAMS

A number of experimental programs have been conducted to measure the infrared spectral radiance of the atmosphere from ground level and balloon platforms. Some of these programs and their experimental results in the 15 μ region are discussed here.

Bell, et al.,(refs. 101 and 102) used a mobile laboratory to take radiance measurements of the sky over the spectral interval from 1 to 20 μ with high spectral resolution (less than 0.25μ) grading spectrometers. Measurements were made in Cocoa Beach, Florida, from Holloman AFB in New Mexico, and from several locations near Colorado Springs, Colorado. It was found that

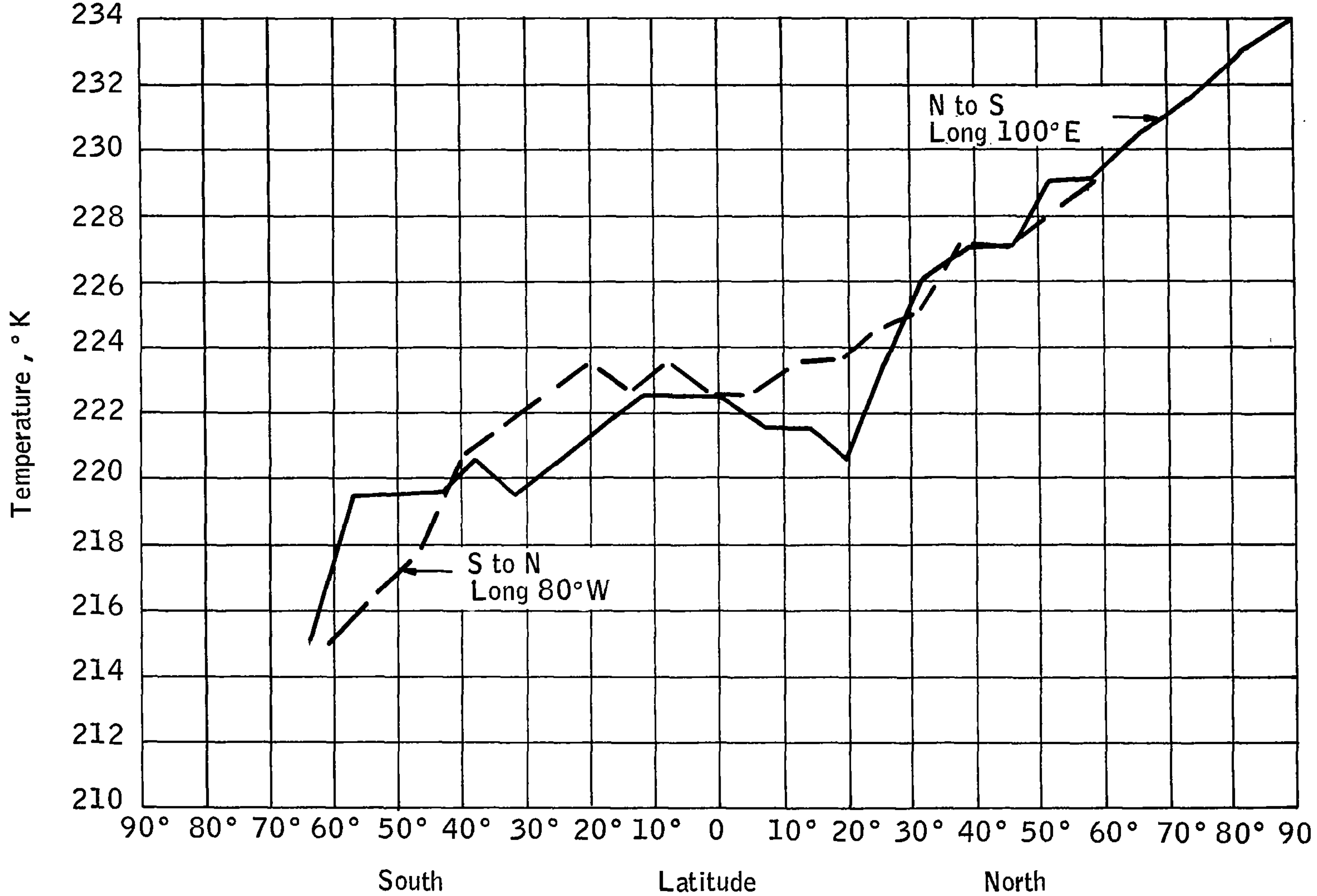

Figure 66. 14 to 16 - Micron Temperatures versus Latitude, Orbit 59

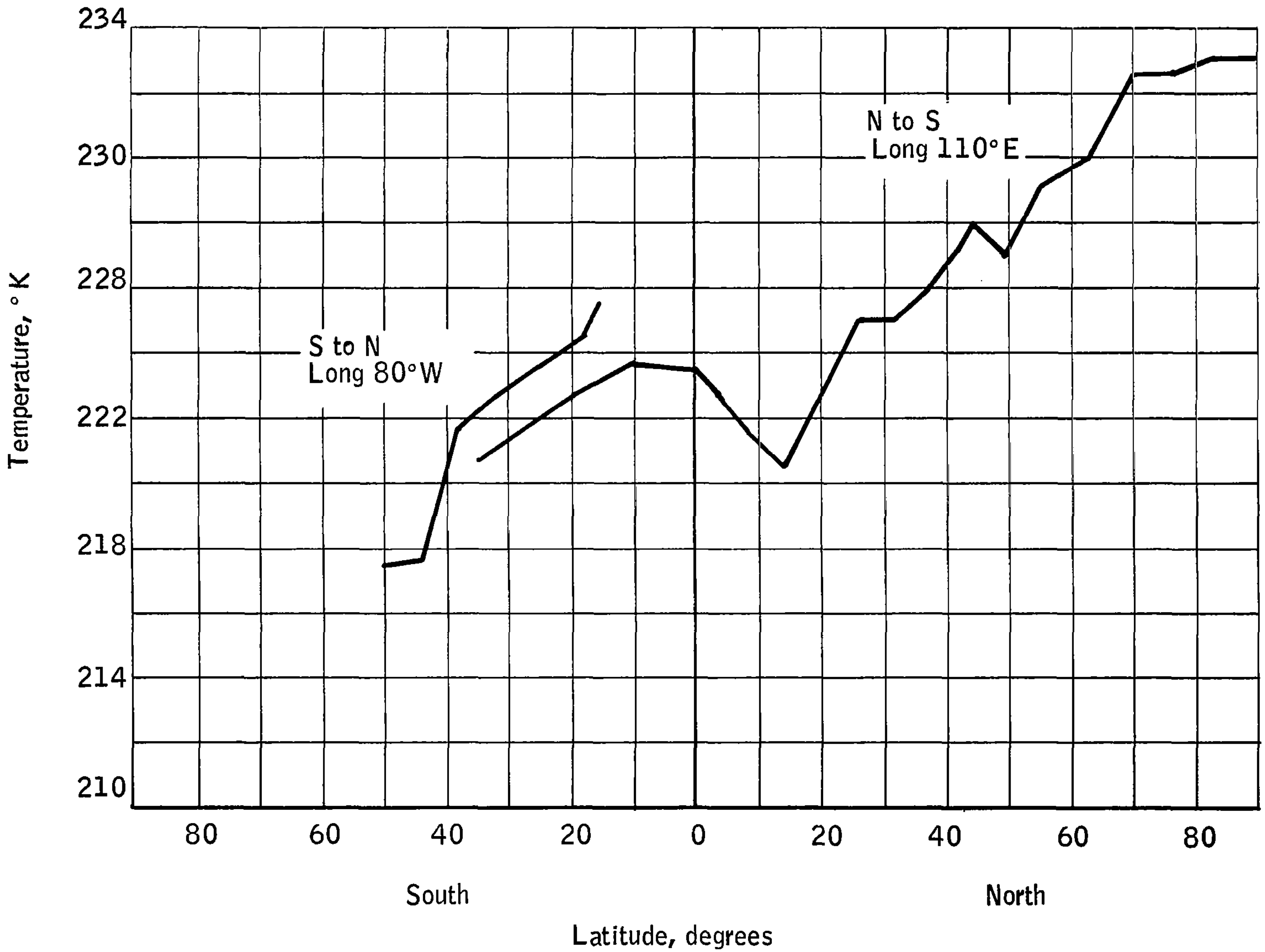

Figure 67. 14 to 16 - Micron Temperatures versus Latitude, Orbit 112

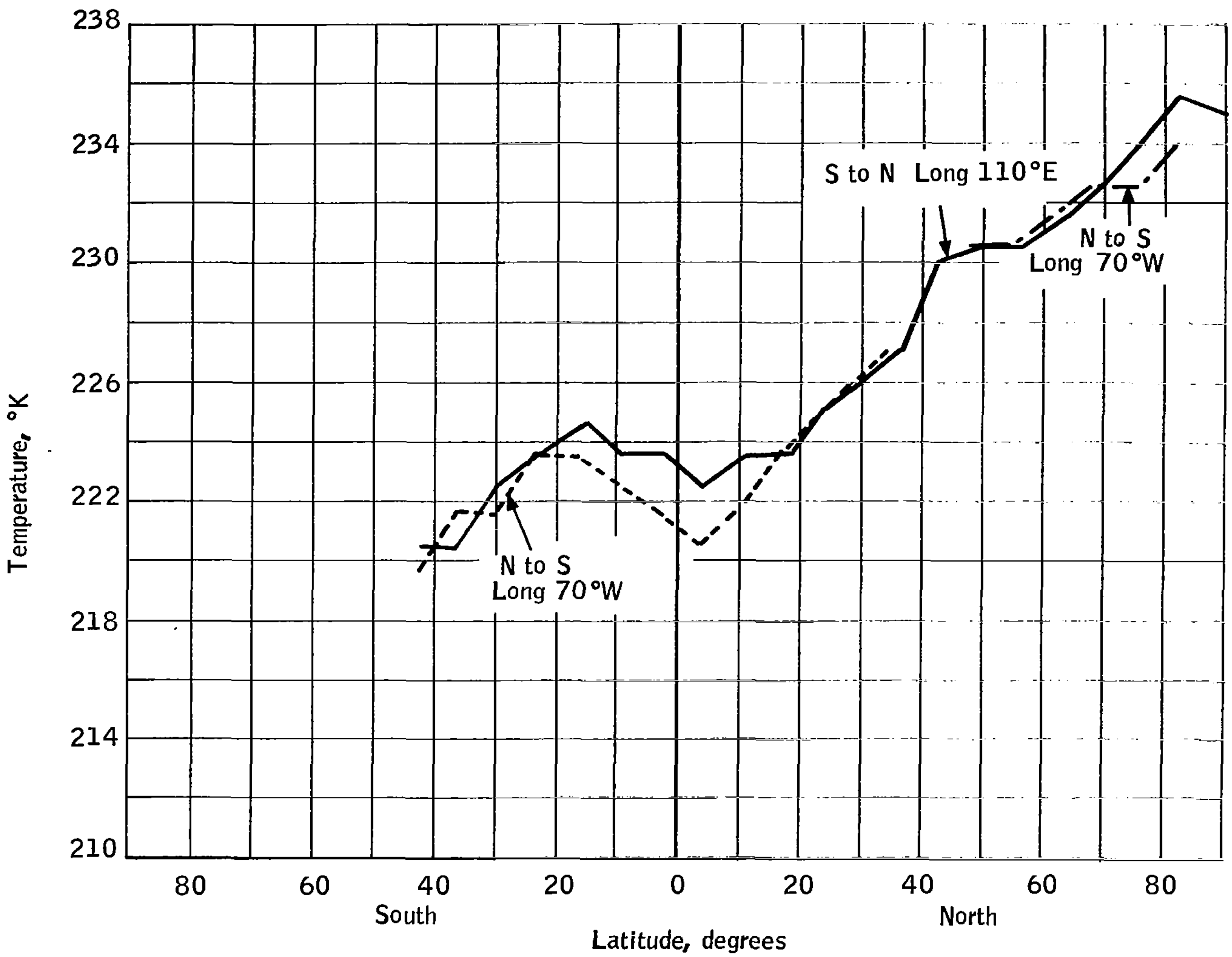

Figure 68. 14 to 16 - Micron Temperatures versus Latitude, Orbit 145

radiance in the 15 μ region was essentially independent of angle of elevation and azimuth angle. It was strongly dependent on ambient temperature. This would be expected, since at ground level the 15 μ region is opaque and the radiance measured would be that emitted from the atmosphere near the observer.

Murcray, et al.,(refs. 103 and 104) and Kyle, et al.,(ref. 105) have conducted several balloon flights with grating and prism spectrometers to obtain experimental data on the infrared spectral transmittance of the atmosphere. The spectral region examined was from 1 to 13 μ. Flights were made from Holloman AFB, New Mexico; Sioux Falls, S. D.; and Fairbanks, Alaska with measurements being taken at altitudes from 1.6 km to 31 km. Although no data was taken in the 15 μ CO_2 region, some confirmation of CO_2 concentrations and theoretical radiance models was obtained by examination of the experimental data in the 4.3 μ CO_2 band.

Chaney (ref. 106) conducted a program with an interference spectrometer on a high altitude balloon flight originating from Sioux Falls, S.D., in June 1963. A float altitude of 34 km was maintained for 11 hours. The spectrometer viewed at an angle of 30° off the nadir and during the flight observed clear sky, partly cloudy sky on both sides of a storm, and high cumulus storm clouds. Measurements were made on the infrared spectral interval from 6.25 μ to 16.7 μ with a spectral resolution varying from 0.2 μ at 6.25 μ to 1.3 μ at 16.7 μ. The CO_2 region around 15 μ exhibited a smooth rapid drop in temperatures to 50 000 ft (15.2 km) with a smaller rise in temperature from 70 000 to 112 000 ft. (21.3 to 34.1 km). The spectrometer response at 14.5 μ as a function of time is shown in Figure 69. At the float altitude, the temperature decreased slowly throughout the day. A significant decrease in temperature was noted in the 15 μ region as the high clouds were scanned, although the decrease for this region was much less than for the other portions of the spectrum.

Zachor and Persky (ref. 107) described a series of balloon flights over New Mexico in which interference spectrometers were used to make atmospheric emission measurements over the 5 to 40 μ spectral region. Unfortunately, equipment problems occurred and the maximum altitude for which data were taken is 54 000 ft (16.5 km). Data were taken in both the nadir direction and at an angle of 30° to the zenith. Two spectrometers were used with one responding in the 5 to 15 μ region and the other in the 9 to 40 μ region. Both had a resolution of 40 cm^{-1}. Considerable scatter and differences between the two spectrometers in the 12 to 15 μ region makes the measurements in the CO_2 region questionable.

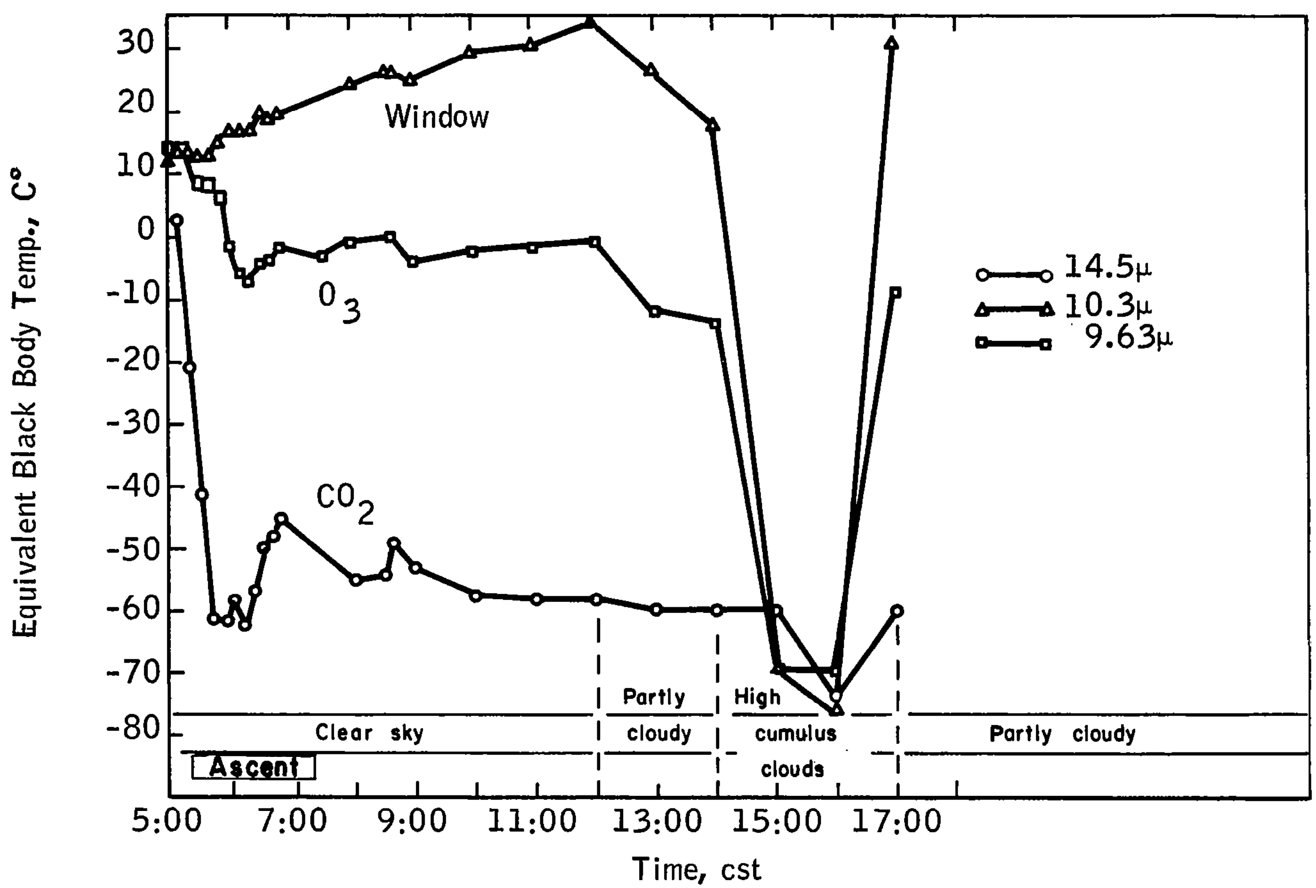

Figure 69. Time Plot of Spectrometer Outputs
[From Ref. 101]

HORIZON SENSOR FLIGHT PERFORMANCE

Infrared horizon sensors have been used as the principal attitude measurement sensor on many spacecraft since 1958. The Earth's infrared horizon varies in altitudes and shape from spectral band to spectral band. In addition, variations are caused in each band by diurnal, seasonal, weather, etc., conditions. Even including all of these variations, spacecraft attitude errors due to the Earth's horizon would be less than one degree. Figure 70 shows the attitude error for spacecrafts at three different altitudes as a function of the error in horizon height. Theoretical and experimental work done to date shows that the infrared horizon in the region from 1 to 30 μ has altitude variations much less than 40 km.

Many problems have been encountered with horizon sensors trying to reach the accuracies predicted for the broad band infrared horizon. Examples of the difficulties are shown in the Mercury MA-5 horizon sensor data shown in Figures 71 through 75. The response characteristics of the sensor are shown in Figure 76. Figure 71 shows the normal scans with negligible cloud effects of sun and cloud interference on the sensor operation. Errors of several degrees have been noted from these effects because the sensors tend to lock on the edges and track disturbances rather than the true horizon. The sensors commonly use a threshold device or similar techniques to define a particular radiance level, normalized radiance level, profile slope, etc., as the horizon. The Mercury sensors used a fixed radiance level. If the sensor scans over the Earth, clouds can cause variations in radiance which will fool the sensor logic system. These are really instrumentation errors since clouds on the true Earth's horizon should never vary the horizon more than the heights of the cloud itself which would normally be much less than 20 km. If the threshold radiance level had been set closer to the space level for the Mercury system or if less of the Earth's region were scanned, the errors due to clouds would have been reduced. However, instrumentation signal-to-noise ratios limit the threshold radiance detection level.

An example of improvement in accuracy by lowering the threshold radiance level can be seen by examining results from the Tiros horizon sensors. On the Tiros series of satellites, sensors in the 2 to 20 μ band and the 8 to 20 μ band were used to determine Earth's horizon crossings and to turn the TV cameras on and off. A threshold sensor was used to define the horizon. Missed horizons were determined by examining the TV data. By decreasing the temperature (radiance) at which threshold occurred significant improvement in horizon detection occurred as can be seen from Table 17.

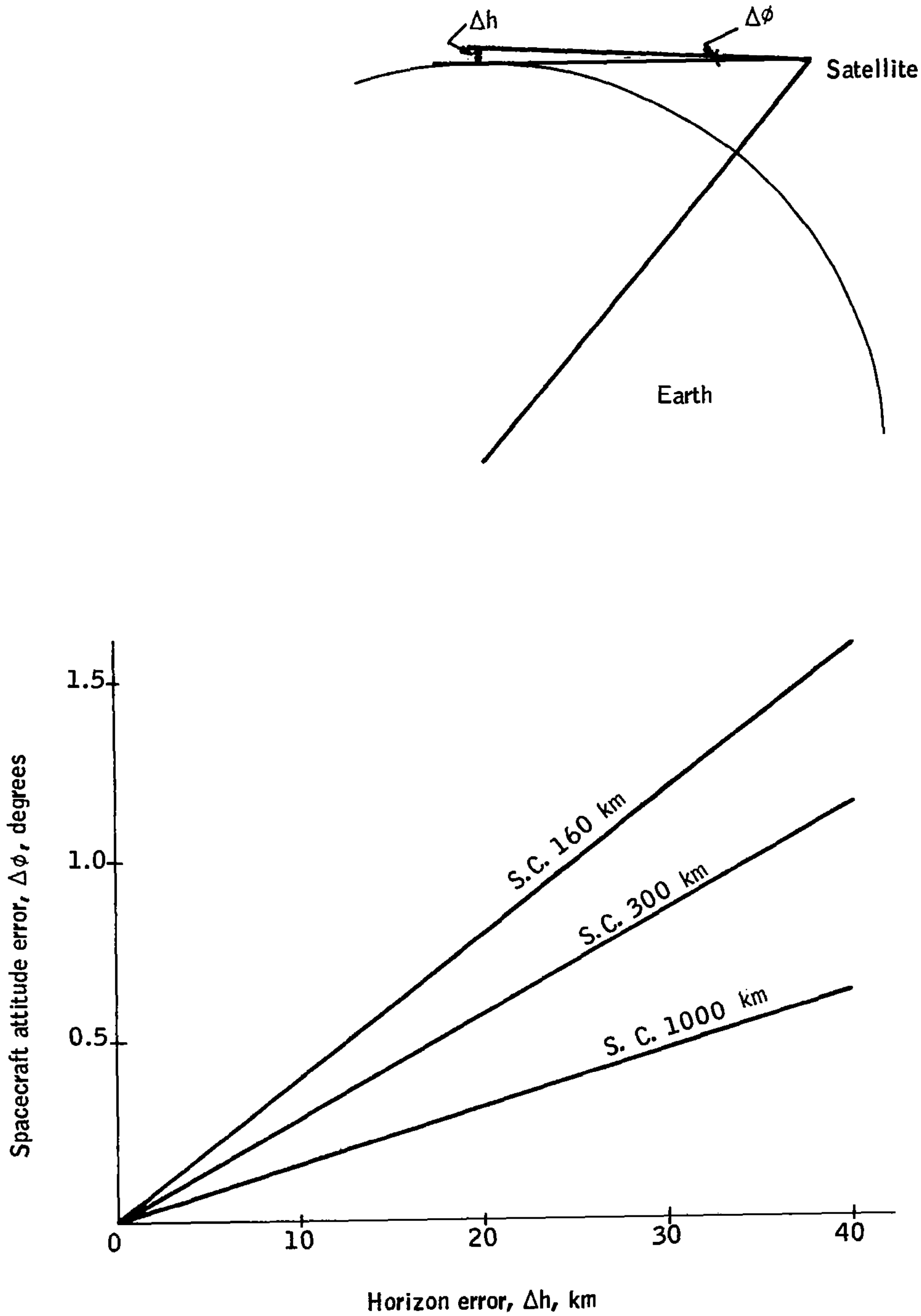

Figure 70. Horizon Error versus Spacecraft Attitude Error

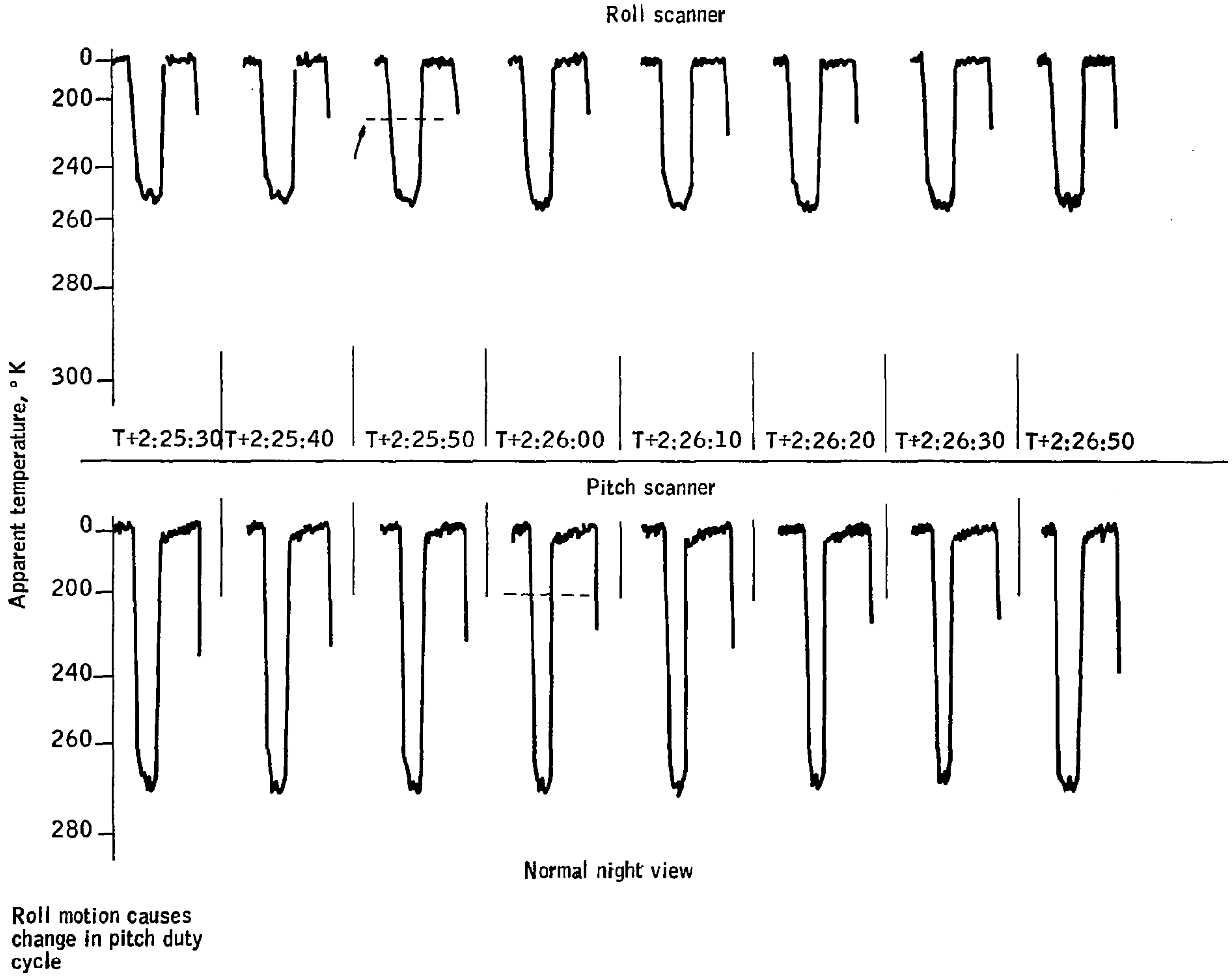

Figure 71. MA-5 Horizon Sensor Outputs, Normal Night View

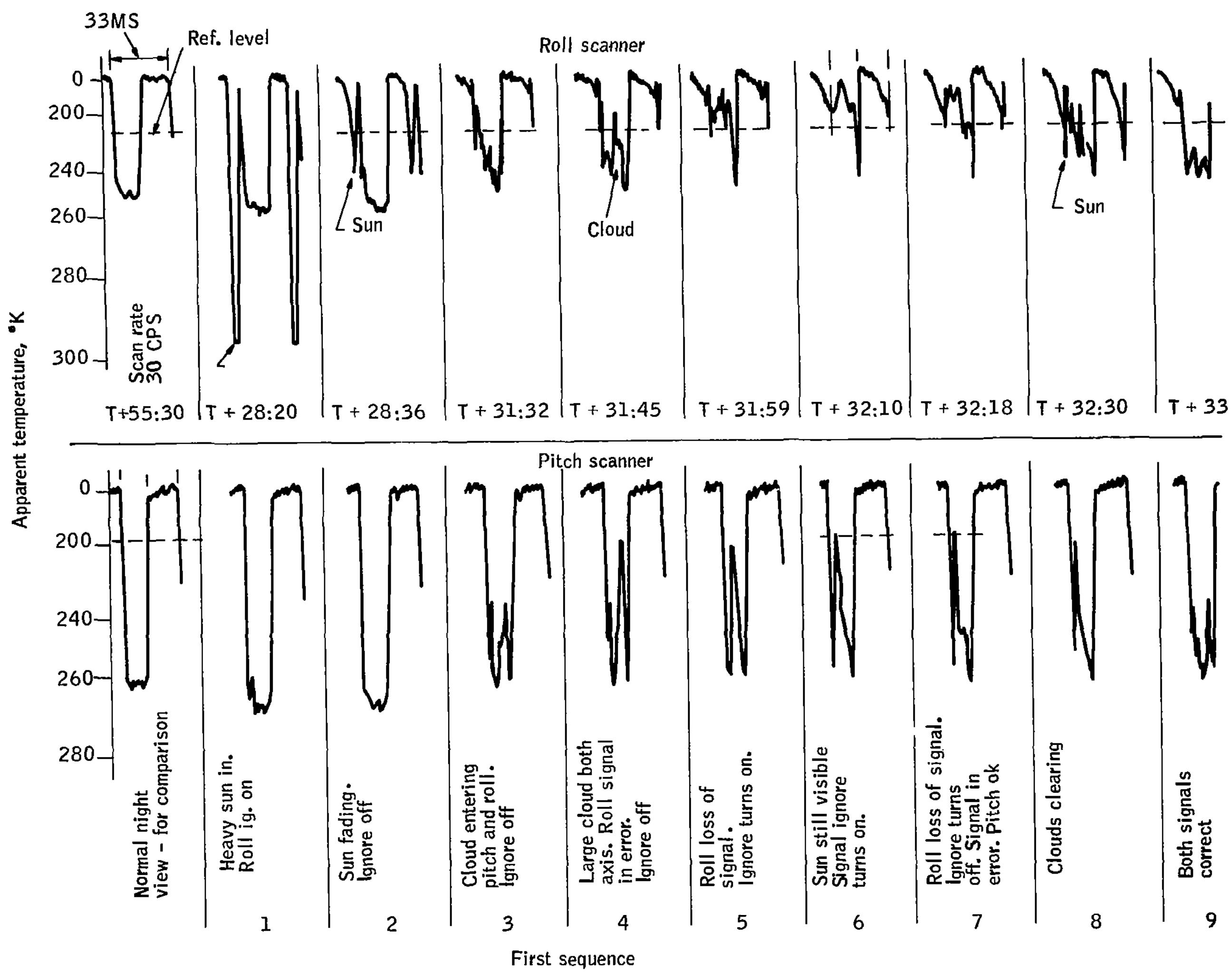

Figure 72. MA-5 Horizon Sensor Outputs, First Sunset Sequence

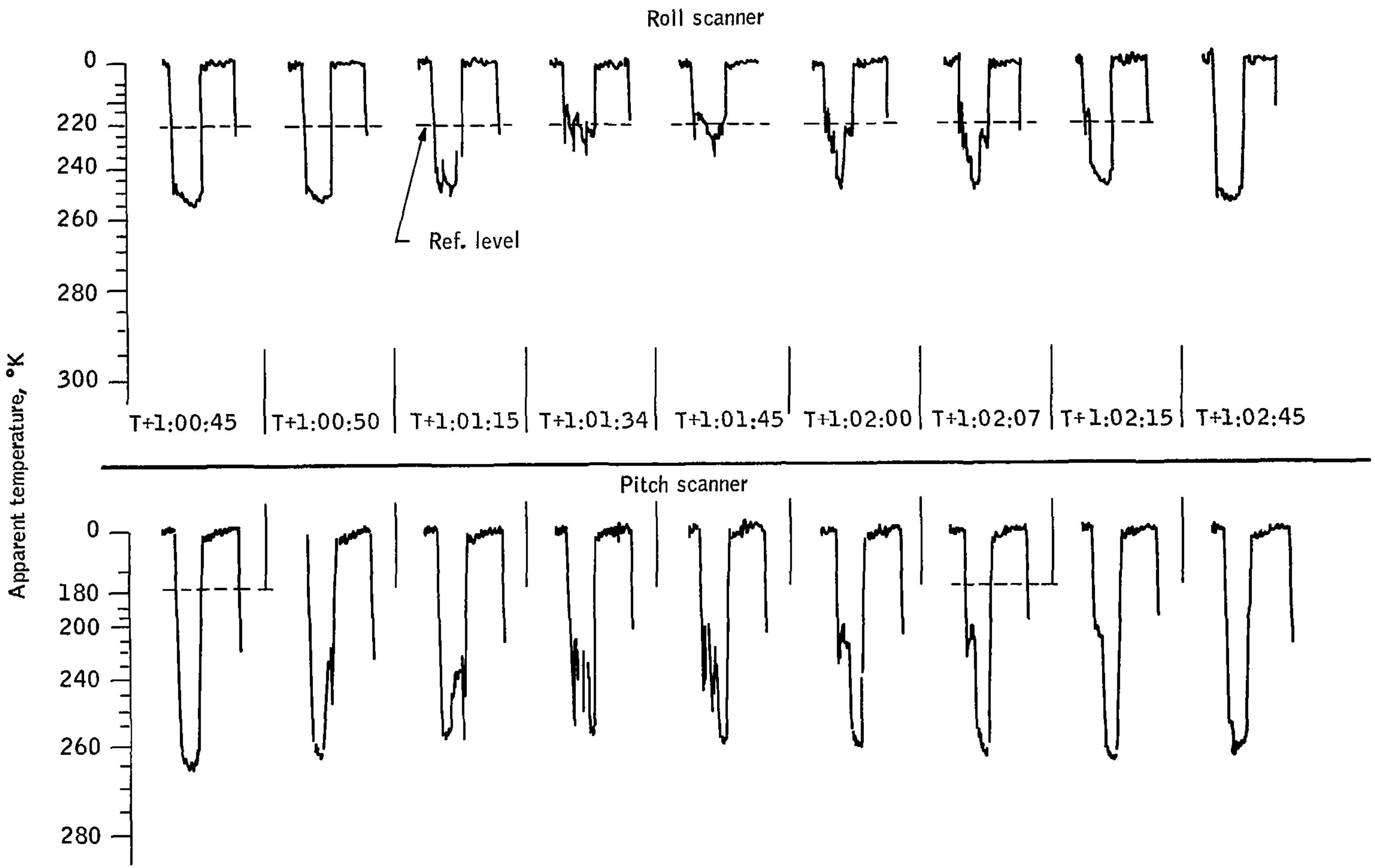

Figure 73. MA-5 Horizon Sensor Outputs, Night Time Cloud Sequence

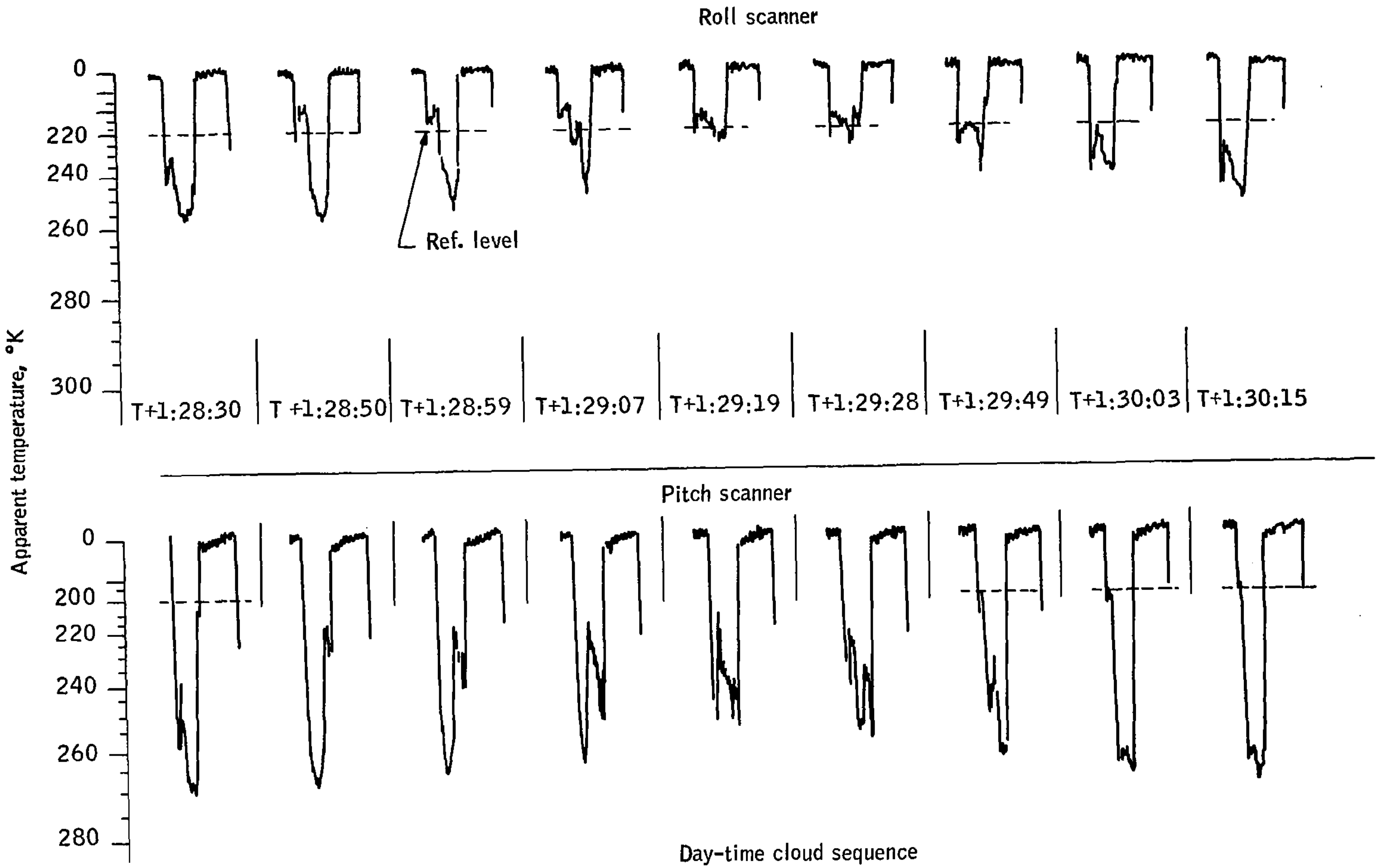

Figure 74. MA-5 Horizon Sensor Outputs, Day Time Cloud Sequence

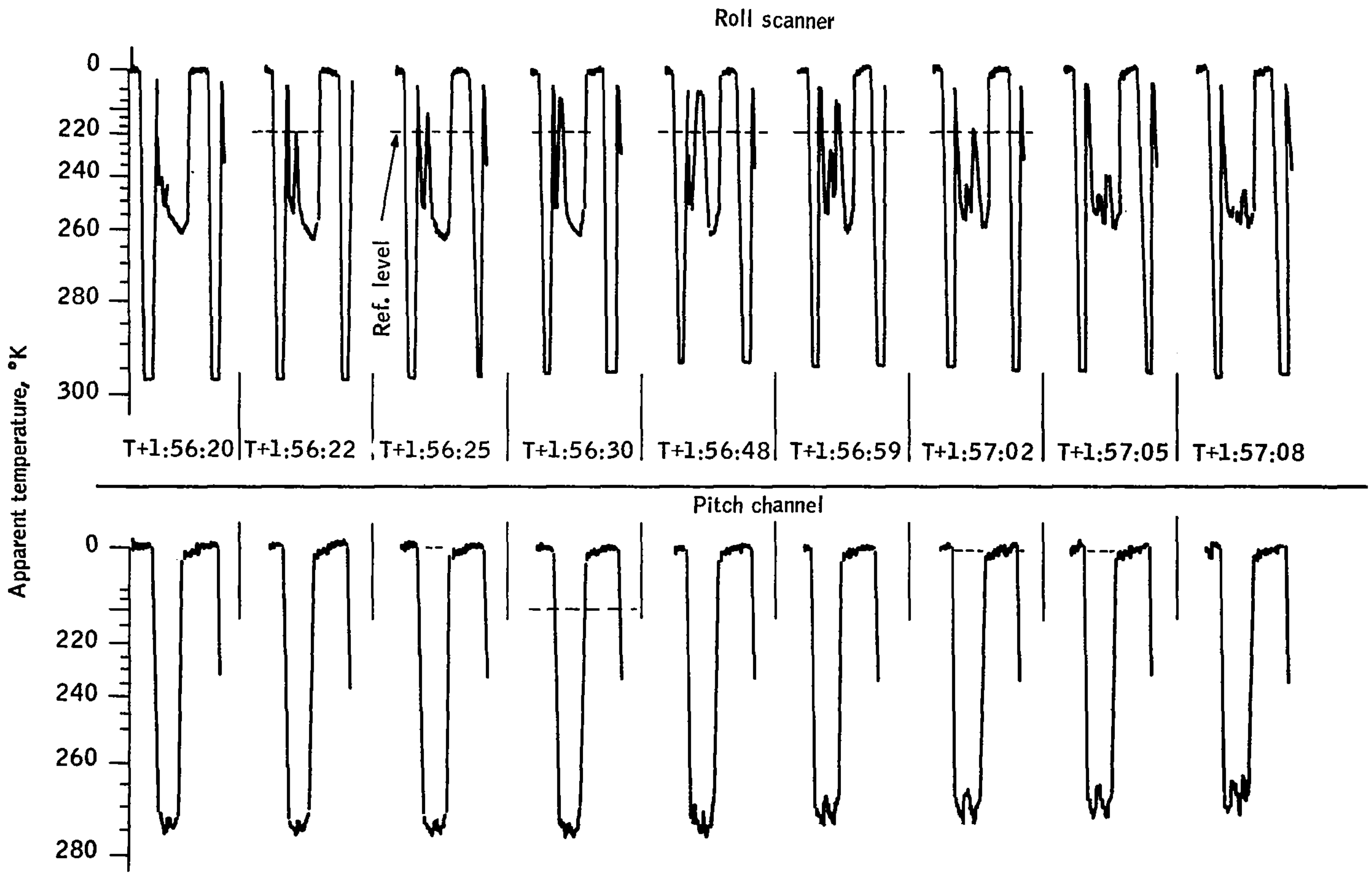

Figure 75. MA-5 Horizon Sensor Outputs, Extra Cold Cloud, Sunset Sequence

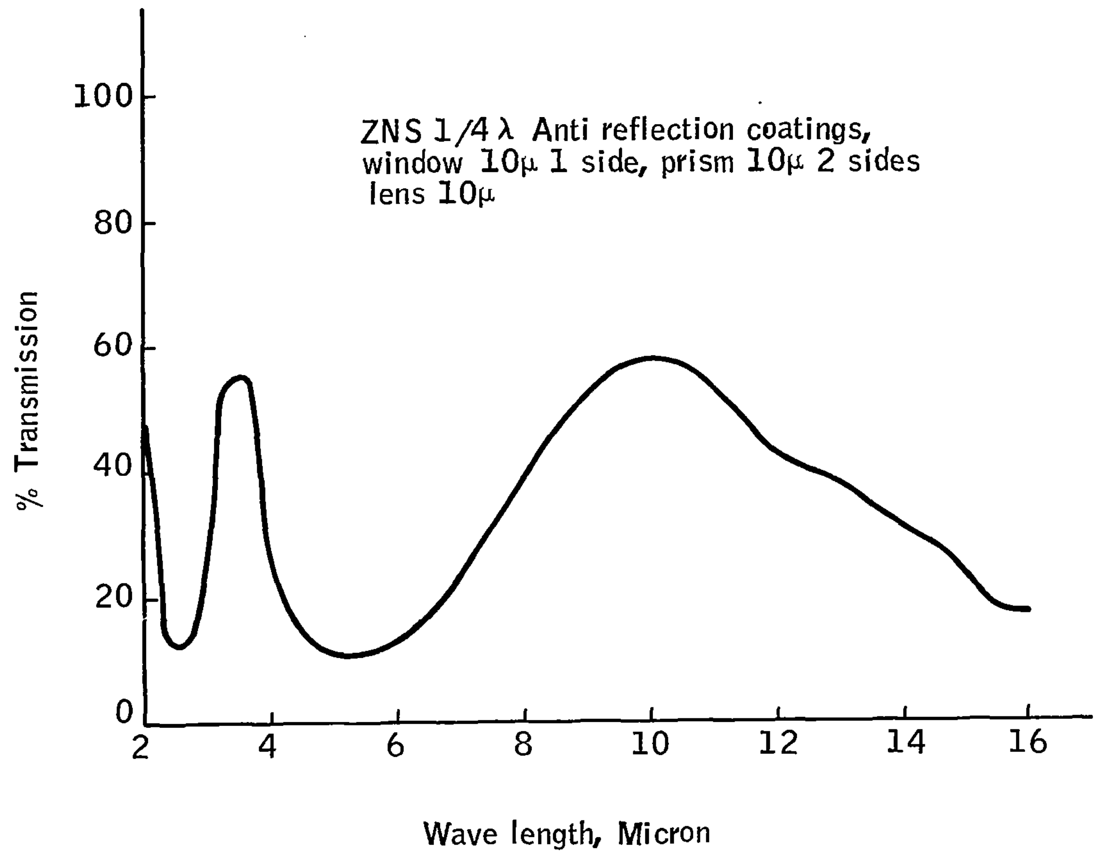

Figure 76. Transmission of Germanium Optics in MA-5 Horizon Sensor
[From Ref. 108]

TABLE 17. - TIROS HORIZON DETECTION DEPENDENCE ON THRESHOLD
[From J. J. Horan, RCA Private Communications]

Threshold Temperature	No. of Missed Horizons
220 °K	1 to 10 per 1000 crossings
205 °K	5 to 10 per 10 000 crossings
200 °K	1 to 10 per 10 000 crossings
180 °K	Essentially none

The horizons for the various infrared spectral bands occur at widely varying altitudes. To obtain better accuracy and reduce the effect of clouds on the sensors, it is logical to filter out the spectral bands contributing the major variations. In general, spectral bands with high altitude horizons show much less cloud or weather variations. Horizons in the 15 μ CO_2 band for five model atmospheres which should produce nearly the extreme variations of radiance is shown in Figure 77. Use of a simple threshold detector on these horizon profiles should produce accuracies much better than 0.5 degrees. Although it has been known for some time that the 15 μ CO_2 spectral region should provide a stable horizon, no horizon sensor systems using only this region have been flown to date. Problems in filter production and operation with the low signal levels from the narrow spectral region have hindered the production of sensors. The Nimbus II horizon sensor uses the 13 to 19 μ spectral region. High clouds have some effect on this sensor; however, the control system response was slowed down to average out much of the cloud variations. Attitude errors due to clouds on the order of one degree are still noted.

Once systems are flight proven for the 14 to 16 μ region, several techniques are available for improving the system accuracy. Normalized tresholds, slope measurement and corrections, second harmonic tracking, etc., have been proposed and are being developed by the sensor manufacturers. As part of the Horizon Definition Study, an analysis was made of many types of horizon locators and their variations over the set of synoptic horizon radiance profiles generated for the 14.0 to 16.3μ spectral interval. This analysis is described in detail in Reference 90. Without exception, the standard deviation and spread decrease as the threshold constant decreases which corresponds to selecting the located horizon at higher altitudes. Thus, system accuracy capabilities are a strong function of instrument sensitivity. This is consistent with the Tiros horizon sensor example discussed earlier in this subsection. Using the technique described in Reference 91, horizon locators within the present state-of-the-art of sensor design can be selected which provide a located horizon standard deviation of less than 1.55 km (0.045° from 300 km orbit).

The horizon errors quoted in the previous paragraph were generated from horizon profiles containing all of the expected seasonal, diurnal, etc., variations. From examination of the curves in Figure 77, it is obvious there is a

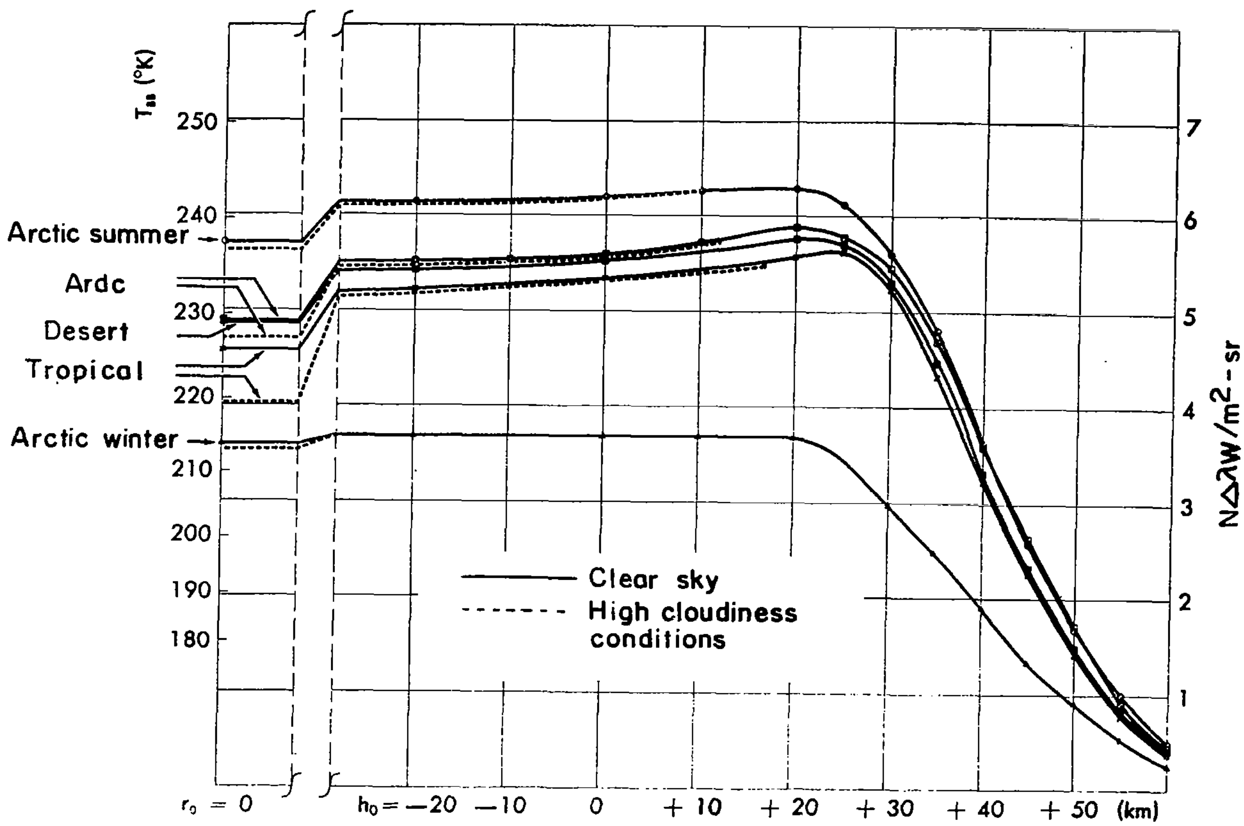

Figure 77. Curves of Radiance in the 15 - Micron CO_2 Band Versus Altitude for Five Model Atmospheres [From Ref. 56]

large systematic seasonal variation. With care, many of the systematic variations could be designed out of the horizon sensor system or compensated for. To separate the systematic from the random variations, horizon radiance profiles were generated from meteorological data for one year at three-day intervals over Cape Kennedy, Florida. A statistical time series analysis done on the horizon locator altitudes for these profiles is described in Reference 89. By fitting the located altitudes with a Fourier time series and removing the systematic variations, the standard deviation for each horizon locator can be significantly reduced. The study has shown that there are systematic variations in the Earth's CO_2 horizon which can be removed to increase accuracies if sufficient measurements are made to determine their characteristics.

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INTRODUCTION

As part of the Horizon Definition Study, a thorough examination of present knowledge in the field was conducted. This examination consisted of making extensive literature searches and directly contacting groups which have done considerable work in the field. The information collected was used to a considerable degree to provide basic data and background information in the course of this study program. The bibliography listed alphabetically by principal author is given in Appendix A.

The literature searches were based on large lists of key words or subjects. Sources searched were the Honeywell Library, University of Minnesota Library, NASA STAR, TAB, DDC, and multiple other aerospace, electronic, and infrared abstracts. In addition, many documents of value to the program were located by examining reference lists in documents already in hand and from direct contact with groups working in the field. Copies of all documents included in the bibliography are entered in a central file or their location is noted such that ready access to the information can be accomplished.

To simplify the filing system and make the bibliography more usable, a computer program was written to maintain and update the file. The program has the following features:

1. Alphabetical listing by principal author
2. Alphabetical listing by source
3. Alphabetical listing of all authors with serial numbers
4. Serial number listing of total bibliography for cross-referencing with 3.
5. Sort and printout by descriptor or combination of descriptors.

The computer program is set up to provide simple entry of additional items, information on items already entered, and to increase the number of descriptors. The bibliography was planned to be carried on and expanded in the next phase of the program.

The format used in the bibliography computer printout was selected to be self-descriptive and to be a standard format for all entries. Because a single format was used for books, periodicals, reports, etc., blank lines or spaces occur in some of the entries. The format is as follows:

Serial No.
Classification

Authors
Title
Source
Report No. or Description
Date   No. of pages
DDC or NASA Abstract No.
Contract No.
Descriptors

In some cases, complete information on items such as Abstract No., Date, or Contract No., was not available. On the philosophy that some information is better than none, these entries were not excluded from the bibliography.

Each entry to the bibliography was examined and descriptors of the subject content of the document were assigned. This allows for easy location and sorting of the bibliography by subject. The total subject (descriptors) listing used for Phase I is as follows:

1. Atmospheric Physics
2. Radiance (Theoretical 15 μ)
3. Radiance (Theoretical other)
4. Radiance (Experimental 15 μ)
5. Radiance (Experimental other)
6. Radiometers
7. Horizon Sensors
8. Attitude Measurement (other than Horizon Sensors)
9. Attitude Control
10. Spacecraft Structure
11. Tracking and Data Acquisition
12. Spacecraft Power Systems
13. Mission Profile
14. Meteorology - Synoptic Studies
15. Meteorology - Raw Data
16. Meteorology - Stratospheric Warmings
17. Meteorology - Statistical Studies
18. Meteorology - Summary Studies
19. Launch Vehicles and Facilities
20. Data Handling
21. Data Reduction

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APPENDIX A
HORIZON DEFINITION STUDY

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EISNER,I. L. , YOUNG,J. B.
OETJEN,R. A. ,
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SOURCE: OHIO STATE UNIVERSITY
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DDC OR NASA NO. 141795
CONTRACT NUMBER AF 33(616)-3312
DESCRIPTORS:
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333. AUTHORS: BELL,E. E.
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CONTRACT NUMBER AF 33(616)-3312
DESCRIPTORS:
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331. AUTHORS: BERNSTEIN,A. B.
YOUNG,J. A. ,
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SOURCE: APPLIED METEOROLOGY JOURNAL
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LUND,I. A. ,
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MIERS,B. T.
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15. METEOROLOGY - RAW DATA

22. AUTHORS: BEYERS,N. J.
THIELE,O. W., WAGNER,N. K.
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SOURCE: U.S. ARMY R AND D
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JONES,E. S. O.
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SOURCE: TELLUS
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ALDER,J. E.
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SOURCE: STANFORD RESEARCH INSTITUTE
REPORT NUMBER/DESCRIPTION: AFCRL-65-211
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DDC OR NASA NO. 616295
CONTRACT NUMBER AF 19(628)-1601
DESCRIPTORS:
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APPROACH TO OBJECTIVE NEPHANALYSIS FROM AN EARTH-ORIENTED SATELLITE
SOURCE: APPLIED METEOROLOGY JOURNAL
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18. METEOROLOGY SUMMARY STUDIES

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18. METEOROLOGY SUMMARY STUDIES

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SOURCE: AIR FORCE SYSTEMS COMMAND
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DDC OR NASA NO.
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DESCRIPTORS:
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SEATON,M. J. , MASSEY,H. S. W. (EDITED BY)
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SOURCE: AIR FORCE SYSTEMS COMMAND
REPORT NUMBER/DESCRIPTION: FTD-TT-65-551, PP 1-9
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PYBUS,E. J. ,
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SOURCE: LOCKHEED MISSILES AND SPACE COMPANY
REPORT NUMBER/DESCRIPTION: AO64189
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395. AUTHORS: BRANETS,V. N.
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SOURCE: COSMIC RESEARCH
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SOURCE: TELLUS
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DESCRIPTORS:
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KEELING,C. D.
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SOURCE: GEOPHYSICAL RESEARCH JOURNAL
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DDC OR NASA NO.
CONTRACT NUMBER AF 04(695)-469
DESCRIPTORS:
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18. AUTHORS: BUELL,C. E.
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KERN,C. D.
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KATSAROS,K. , KREISS,K.
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SOURCE: UNIVERSITY OF WASHINGTON
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DDC OR NASA NO. CR-68294
CONTRACT NUMBER NASA NSG-632
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)

194. AUTHORS: BUNKER-RAMO CORPORATION
□ BUNKER-RAMO HORIZON SENSOR
SOURCE: BUNKER-RAMO CORPORATION
REPORT NUMBER/DESCRIPTION:
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95. AUTHORS: BURN,J. W.
□ INFRARED HORIZONS FOR MODEL ATMOSPHERES OF THE EARTH
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
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□ AMOUNT OF CARBON DIOXIDE IN THE ATMOSPHERE
SOURCE: TELLUS
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CONTRACT NUMBER AF 33(657)-10107
DESCRIPTORS:
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135. AUTHORS: CARPENTER,R. O.
WIGHT,J. A. QUESADA,A.
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DATE: 1 NOVEMBER 1957 62PP
DDC OR NASA NO. 150825
CONTRACT NUMBER AF19(604)-2405
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18. METEOROLOGY SUMMARY STUDIES

104. AUTHORS: CAVENEY,R. D.
□ SECOND-HARMONIC EDGE-TRACKER HORIZON SENSOR, FIXED-POINT TYPE
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
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DESCRIPTORS:
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SOURCE: CAMBRIDGE RESEARCH LAB.(AF)
REPORT NUMBER/DESCRIPTION: AFCRL-65-443
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177. AUTHORS: CHAMPION,K. S. W.
MINZNER,R. A.
□ PROPOSED REVISION OF U.S. STANDARD ATMOSPHERE 90 TO 700 KM
SOURCE: CAMBRIDGE RESEARCH LABORATORIES(AIR FORCE)
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DESCRIPTORS:
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27. AUTHORS: CHANEY, L. W.
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□ALTITUDE BALLOON
SOURCE: PROC.-THIRD SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT
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DATE: FEBRUARY 1965 20PP
DDC OR NASA NO.
CONTRACT NUMBER NASR-54(03)
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SOURCE: MONTHLY WEATHER REVIEW
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DESCRIPTORS:
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431. AUTHORS: CLARK,G.
MCCOY,J. G.
MEASUREMENT OF STRATOSPHERIC TEMPERATURE
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 4, NO. 3, PP 365-370
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DESCRIPTORS:
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407. AUTHORS: CLAUSS,J. R.
RELATIONSHIP BETWEEN TOTAL CLOUD AMOUNTS AND OBJECTIVELY
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SOURCE: UNIVERSITY OF BERLIN
REPORT NUMBER/DESCRIPTION: AFCRL-63-868
DATE: 15 FEBRUARY 1963 74PP
DDC OR NASA NO. 415322
CONTRACT NUMBER AF 61(052)-544
DESCRIPTORS:
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113. AUTHORS: COLE,A. E.
KANTOR,A. J.
AIR FORCE INTERIM SUPPLEMENTAL ATMOSPHERES TO 90 KILOMETERS
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
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KANTOR,A. J.
HORIZONTAL AND VERTICAL DISTRIBUTIONS OF ATMOSPHERIC DENSITY,
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28. AUTHORS: COLLINGE,J. P.
HAYNIE,W. H.
MEASUREMENT OF 15-MICRON HORIZON RADIANCE FROM A SATELLITE
SOURCE: EASTMAN KODAK COMPANY
REPORT NUMBER/DESCRIPTION: 7-3112
DATE: 1 MARCH 1963 56PP
DDC OR NASA NO.
CONTRACT NUMBER AF04(695)-160
DESCRIPTORS:
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29. AUTHORS: COLLIS,R. T. H.
□ CLEAR AIR TURBULENCE DETECTION
SOURCE: IEEE SPECTRUM
REPORT NUMBER/DESCRIPTION: PP 56-61
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235. AUTHORS: COMMITTEE ON EXT. TO THE STD. ATMOSPHERE
□ U. S. STANDARD ATMOSPHERE, 1962- ICAO STANDARD ATMOSPHERE TO 20
□KILOMETERS, PROPOSED ICAO EXTENSION TO 32 KILOMETERS, TABLES AND
□DATA TO 700 KILOMETERS
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION:
DATE: 1962 278PP
DDC OR NASA NO. 401813

DESCRIPTORS:
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17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

103. AUTHORS: CONRATH,B. J.
□ EARTH SCAN ANALOG SIGNAL RELATIONSHIPS IN THE TIROS RADIATION
□EXPERIMENT AND THEIR APPLICATION TO THE PROBLEM OF HORIZON
□SENSING
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION:
DATE: JUNE 1962 21PP
DDC OR NASA NO. TND-1341

DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS
7. HORIZON SENSORS

242. AUTHORS: CORLISS,W. R.
□ SPACE PROBES AND PLANETARY EXPLORATION
SOURCE: D. VAN NOSTRAND COMPANY,INC.
REPORT NUMBER/DESCRIPTION:
DATE: 1965 542PP
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8. ATT MEASMT (EXCL HORIZON SENSORS)
9. ATTITUDE CONTROL
10. SPACECRAFT STRUCTURE
11. TRACKING AND DATA ACQUISITION
12. SPACECRAFT POWER SYSTEMS
13. MISSION PROFILE
19. LAUNCH VEHICLES AND FACILITIES
20. DATA HANDLING

31. AUTHORS: CRAIG,R. A.
HERING,W. S.
□ STRATOSPHERIC WARMING OF JANUARY-FEBRUARY 1957
SOURCE: METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 16,NO.2, PP 91-107
DATE: APRIL 1959 17PP
DDC OR NASA NO.

DESCRIPTORS:
16. METEOROLOGY - STRATO WARMINGS

23. AUTHORS: CRAMER, W. P.
INVESTIGATION OF TIME CHANGES IN CLOUDS OBSERVED OVER THE GULF OF MEXICO AND CARIBBEAN SEA DURING THE PERIOD 18-23 JULY 1961
SOURCE: TEXAS A+M UNIVERSITY
REPORT NUMBER/DESCRIPTION:
DATE: MAY 1963 82PP
DDC OR NASA NO. 415811
CONTRACT NUMBER AF 19(604)-8450
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

32. AUTHORS: CRUTCHER, H. L.
BAER, L.
COMPUTATIONS FROM ELLIPTICAL WIND DISTRIBUTION STATISTICS
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 1, PP 522-530
DATE: DECEMBER 1962 09PP
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17. METEOROLOGY -STATISTICAL STUDIES

274. AUTHORS: CURTIS, A. R.
GOODY, R. M.
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DDC OR NASA NO.

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2. RADIANCE (THEORETICAL 15 U)
18. METEOROLOGY SUMMARY STUDIES

384. AUTHORS: DAVE, J. V.
MATEER, C. L.
DETERMINATION OF OZONE PARAMETERS FROM MEASUREMENTS OF THE RADIATION BACKSCATTERED BY THE EARTHS ATMOSPHERE
SOURCE: NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
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DATE: 29PP
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DESCRIPTORS:
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236. AUTHORS: DAVIS, P. A.
VIEZEE, W.
MODEL FOR COMPUTING INFRARED TRANSMISSION THROUGH ATMOSPHERIC WATER VAPOR AND CARBON DIOXIDE
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
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DDC OR NASA NO.
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18. METEOROLOGY SUMMARY STUDIES

391. AUTHORS: DAVIS, P. A.
VIEZEE, W.
MODEL FOR COMPUTING INFRARED TRANSMISSION THROUGH ATMOSPHERIC WATER VAPOR AND CARBON DIOXIDE
SOURCE: STANFORD RESEARCH INSTITUTE
REPORT NUMBER/DESCRIPTION: SRI 4196
DATE: MARCH 1964 25PP
DDC OR NASA NO. N65-27293
CONTRACT NUMBER NAS 5-2919
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18. METEOROLOGY SUMMARY STUDIES

248. AUTHORS: DAVIS, W. D.
□ COMPUTER PROGRAM TO IMPROVE STADAN STATION SCHEDULING
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION:
DATE: APRIL 1966 36PP
DDC OR NASA NO. TM X-1230

DESCRIPTORS:
11. TRACKING AND DATA ACQUISITION

34. AUTHORS: DE FRIES, P. J.
□ HORIZON SENSOR PERFORMANCE IN MEASURING ALTITUDE ABOVE THE MOON
SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: JULY 1961 20PP
DDC OR NASA NO. TN-D-609

DESCRIPTORS:
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338. AUTHORS: DE MICHAELS, R. E.
□ ANALYSIS OF NUMERICAL CLOUD FORECASTS
SOURCE: ST. LOUIS UNIVERSITY
REPORT NUMBER/DESCRIPTION:
DATE: 1965 51PP
DDC OR NASA NO. 620439
CONTRACT NUMBER AF 33(608)-1115
DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

33. AUTHORS: DEAN, C.
□ ATTITUDE DETERMINATION FROM TIROS PHOTOGRAPHS
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION:
DATE: MAY 1964 34PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 5-1204
DESCRIPTORS:
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422. AUTHORS: DESHPANDE, D. V.
□ HEIGHTS OF TOPS OF CB CLOUDS OVER INDIA
SOURCE: INDIAN JOURNAL OF METEOROLOGY AND GEOPHYSICS
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DATE: JANUARY 1961 4PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

423. AUTHORS: DE, A. C
□ UNUSUALLY HIGH NORWESTER RADAR CLOUD
SOURCE: INDIAN JOURNAL OF METEOROLOGY AND GEOPHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 10, NO. 3, PP 359-360
DATE: JULY 1959 2PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

334. AUTHORS: DE, A. C.
□ HIGH RADAR CLOUDS ABOVE 10KM
SOURCE: INDIAN JOURNAL OF METEOROLOGY AND GEOPHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 14, NO. 3, PP 327-330
DATE: JULY 1963 4PP
DDC OR NASA NO.

DESCRIPTORS:
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421. AUTHORS: DE,A. C.
RAKSHIT,D. K.
□ RADAR OBSERVATIONS ON THE FORMATION OF CUMULUS CLOUDS NEAR
□CALCUTTA DURING THE MONSOON SEASON
SOURCE: INDIAN JOURNAL OF METEOROLOGY AND GEOPHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 12,NO. 2, PP 289-298
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18. METEOROLOGY SUMMARY STUDIES

109. AUTHORS: DODGEN,J. A.
CURFMAN,H. J.
□ SUMMARY OF HORIZON DEFINITION STUDIES BEING UNDERTAKEN BY
□LANGLEY RESEARCH CENTER
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 233-239
DATE: 1965 7PP
DDC OR NASA NO.

DESCRIPTORS:
2. RADIANCE (THEORETICAL 15 U)
4. RADIANCE (EXPERIMENTAL 15 U)

197. AUTHORS: DOUGLAS AIRCRAFT CO., INC.
□ DELTA LAUNCH VEHICLE
SOURCE: DOUGLAS AIRCRAFT CO., INC.
REPORT NUMBER/DESCRIPTION: SM-43616
DATE: JUNE 1963 45PP
DDC OR NASA NO.

DESCRIPTORS:
19. LAUNCH VEHICLES AND FACILITIES

198. AUTHORS: DOUGLAS AIRCRAFT CO., INC.
□ DELTA SPACECRAFT DESIGN RESTRAINTS
SOURCE: DOUGLAS AIRCRAFT CO., INC.
REPORT NUMBER/DESCRIPTION: SM-42367
DATE: JULY 1964 80PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 7-220
DESCRIPTORS:
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19. LAUNCH VEHICLES AND FACILITIES

199. AUTHORS: DOUGLAS AIRCRAFT CO., INC.
□ DELTA AND IMPROVED DELTA DESIGN AND CAPABILITIES
SOURCE: DOUGLAS AIRCRAFT CO., INC.
REPORT NUMBER/DESCRIPTION: SM-45243
DATE: AUGUST 1964
DDC OR NASA NO.

DESCRIPTORS:
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35. AUTHORS: DRAYSON,S. R.
□ ATMOSPHERIC TRANSMISSION IN THE CO(2) BANDS BETWEEN 12 MICRONS
□AND 18 MICRONS
SOURCE: APPLIED OPTICS
REPORT NUMBER/DESCRIPTION: VOL. 5,NO.3,PP 385-391
DATE: MARCH 1966 07PP
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DESCRIPTORS:
2. RADIANCE (THEORETICAL 15 U)
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211. AUTHORS: DRAYSON, S. R.
□ ATMOSPHERIC SLANT PATH TRANSMISSION IN THE 15-MICRON CO(2) BAND
SOURCE: MICHIGAN, UNIVERSITY OF
REPORT NUMBER/DESCRIPTION:
DATE: APRIL 1965 104PP
DDC OR NASA NO. TN D-2744
CONTRACT NUMBER NASR-54(03)
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

306. AUTHORS: DUCHON, C. E.
STEPHENS, J. J. , JEHN, K. H.
□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM - □QUARTERLY TECHNICAL REPORT NO. 21
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JULY 1965-30 SEPTEMBER 1965 6PP
DDC OR NASA NO. 479097
CONTRACT NUMBER DA-23-072-AMC-1564(R)
DESCRIPTORS:
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36. AUTHORS: DUNCAN, J.
□ HORIZON DETECTION TECHNIQUES PROVIDING 0.05 DEGREES ACCURACY □AT LOW SATELLITE ALTITUDES
SOURCE: PROCEDURES IRIS
REPORT NUMBER/DESCRIPTION: VOL. 9, NO. 1, PP 155-159
DATE: JANUARY 1964
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DESCRIPTORS:
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7. HORIZON SENSORS

56. AUTHORS: DUNCAN, J.
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SOURCE: UNIVERSITY OF MICHIGAN
REPORT NUMBER/DESCRIPTION: 2389-80-T1
DATE: APRIL 1965 44PP
DDC OR NASA NO.
CONTRACT NUMBER NONR 1224(12)
DESCRIPTORS:
6. RADIOMETERS
7. HORIZON SENSORS

40. AUTHORS: DUNCAN, J. W.
WOLFE, W. , OPPEL, G. F.
BURN, J. ,
□ INFRARED HORIZON SENSORS
SOURCE: UNIVERSITY OF MICHIGAN
REPORT NUMBER/DESCRIPTION: 2389-80-T
DATE: APRIL 1965 314PP
DDC OR NASA NO. NAVSC P-2481
CONTRACT NUMBER NONR 1224(12)
DESCRIPTORS:
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3. RADIANCE (THEORETICAL OTHER)
4. RADIANCE (EXPERIMENTAL 15 U)
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7. HORIZON SENSORS

275. AUTHORS: DUTSCH,H. U.
¤ OZONE AND GENERAL CIRCULATION IN THE STRATOSPHERE-FINAL REPORT:
¤VERTICAL OZONE DISTRIBUTION OVER AROSA
SOURCE: CAMBRIDGE RESEARCH CENTER(AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRC-TR-59-290
DATE: SEPTEMBER 1959 45PP
DDC OR NASA NO. 230332
CONTRACT NUMBER AF 61(514)-905
DESCRIPTORS:
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358. AUTHORS: DUTSCH,H. U.
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¤DECEMBER 1964
SOURCE: LICHTKLIMATISCHES OBSERVATORIUM
REPORT NUMBER/DESCRIPTION: AFCRL-65-419
DATE: MARCH 1965 72PP
DDC OR NASA NO. 619251
CONTRACT NUMBER AF-EOAR 62-115
DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

41. AUTHORS: EARLE,M. D.
¤ INFRARED HORIZON SENSOR ACCURACY IN THE ATMOSPHERIC ABSORPTION
¤BANDS
SOURCE: AEROSPACE CORPORATION
REPORT NUMBER/DESCRIPTION:
DATE: JUNE 1964 41PP
DDC OR NASA NO. 460971
CONTRACT NUMBER AF 04(695)-269
DESCRIPTORS:
7. HORIZON SENSORS

CONF. 55. AUTHORS: EARLE,M. D.
¤ HORIZON SENSORS AND HORIZON PROFILE MEASUREMENTS
SOURCE: AEROSPACE CORPORATION
REPORT NUMBER/DESCRIPTION: TDR-469(5107-38)-1
DATE: FEBRUARY 1965 24PP
DDC OR NASA NO. 358668
CONTRACT NUMBER AF 04(695)-469
DESCRIPTORS:
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4. RADIANCE (EXPERIMENTAL 15 U)
7. HORIZON SENSORS

304. AUTHORS: EDDY,A.
STEPHENS,J. J. , HARAGAN,D. R.
JEHN,K. H. ,
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¤QUARTERLY TECHNICAL REPORT NO. 17
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JULY 1964-30 SEPTEMBER 1964 21PP
DDC OR NASA NO. 479093
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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305. AUTHORS: EDDY,A.
STEPHENS,J. J. , DUCHON,C. E.
JEHN,K. H. ,
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¤QUARTERLY TECHNICAL REPORT NO. 19
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REPORT NUMBER/DESCRIPTION:
DATE: 1 JANUARY 1965-31 MARCH 1965 17PP
DDC OR NASA NO. 479095
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

356. AUTHORS: EDDY, A.
STEPHENS, J. J. , HARAGAN, D. R.
JEHN, K. H. ,
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SOURCE: UNIVERSITY OF TEXAS
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DATE: 1 OCTOBER 1964-31 DECEMBER 1964 9PP
DDC OR NASA NO. 479094
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
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310. AUTHORS: EHLERS, D. F.
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SOURCE: PROC. - SECOND SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT
REPORT NUMBER/DESCRIPTION: 4864-3-X, PP 235-265
DATE: FEBRUARY 1963 31PP
DDC OR NASA NO.
CONTRACT NUMBER NONR 1224(44)
DESCRIPTORS:
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7. HORIZON SENSORS
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346. AUTHORS: ELSASSER, W. M.
CULBERTSON, M. F. ,
ATMOSPHERIC RADIATION TABLES
SOURCE: METEOROLOGICAL MONOGRAPHS
REPORT NUMBER/DESCRIPTION: VOL. 4, NO. 23, PP 1-43
DATE: AUGUST 1960 43PP
DDC OR NASA NO.

DESCRIPTORS:
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253. AUTHORS: ELTERMAN, L.
PARAMETERS FOR ATTENUATION IN THE ATMOSPHERIC WINDOWS FOR
FIFTEEN WAVELENGTHS
SOURCE: APPLIED OPTICS
REPORT NUMBER/DESCRIPTION: VOL. 3, NO. 6, PP 745-749
DATE: JUNE 1964 05PP
DDC OR NASA NO.

DESCRIPTORS:
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17. METEOROLOGY -STATISTICAL STUDIES
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255. AUTHORS: ELTERMAN, L.
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VISIBLE, AND INFRARED REGIONS FOR ALTITUDES TO 50 KM
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL-64-740
DATE: SEPTEMBER 1964 45PP
DDC OR NASA NO.

DESCRIPTORS:
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17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

42. AUTHORS: EPSTEIN, E. S.
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SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 1, PP 169-177
DATE: JUNE 1962 09PP
DDC OR NASA NO.

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES

320. AUTHORS: ESSENWANGER, O.
HAGGARD, G.
FREQUENCY OF CLOUDS IN HEIGHT LAYERS FOR BERLIN (TEMPELHOF)
SOURCE: U. S. ARMY ORDNANCE MISSILE COMMAND
REPORT NUMBER/DESCRIPTION: VOL. 1, PP 560-569
DATE: DECEMBER 1962 10PP
DDC OR NASA NO.

DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

360. AUTHORS: EWEN KNIGHT CORP.
OXYGEN HORIZON SEEKER, THEORETICAL ANALYSIS
SOURCE: EWEN KNIGHT CORP.
REPORT NUMBER/DESCRIPTION: AFCRL-64-141
DATE: 14 FEBRUARY 1964 47PP
DDC OR NASA NO. 600783
CONTRACT NUMBER AF 19(628)-3239
DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
7. HORIZON SENSORS

43. AUTHORS: FAIRE, A. C.
CHAMPION, K. S. W.
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AND PRESSURE UP TO 115 KM
SOURCE: SPACE RESEARCH V
REPORT NUMBER/DESCRIPTION: VI.15
DATE: 1965 19PP
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DESCRIPTORS:
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44. AUTHORS: FALBEL, G.
ASTHEIMER, R. W.
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APPROACHES
SOURCE: AIAA GUIDANCE AND CONTROL CONFERENCE
REPORT NUMBER/DESCRIPTION: 63-358
DATE: 1963 14PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS

101. AUTHORS: FALBEL, G.
HIGH-ACCURACY HORIZON SENSOR USING FIRM
SOURCE: PROC. FIRST SYM. INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 159-174
DATE: 1965 16PP
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DESCRIPTORS:
7. HORIZON SENSORS

45. AUTHORS: FAUST, H.
CELL STRUCTURE OF THE ATMOSPHERE- DELIBERATIONS ON ENERGY
ASPECTS OF LARGE-SCALE CIRCULATIONS
SOURCE: U. S. ARMY-EUROPEAN RESEARCH OFFICE
REPORT NUMBER/DESCRIPTION:
DATE: NOVEMBER 1963 15PP
DDC OR NASA NO. 433768
CONTRACT NUMBER DA-91-591-EUC-2847
DESCRIPTORS:
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46. AUTHORS: FAUST,H.
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SOURCE: U. S. ARMY-EUROPEAN RESEARCH OFFICE
REPORT NUMBER/DESCRIPTION:
DATE: JUNE 1965 22PP
DDC OR NASA NO.
CONTRACT NUMBER DA 91-591-EUC-3384
DESCRIPTORS:
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47. AUTHORS: FAUST,H.
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□UP TO A HEIGHT OF 25 KM BETWEEN SAN JUAN AND ALBROOK
SOURCE: U. S. ARMY-EUROPEAN RESEARCH OFFICE
REPORT NUMBER/DESCRIPTION:
DATE: JANUARY 1965 23PP
DDC OR NASA NO.
CONTRACT NUMBER DA 91-591-EUC-3237
DESCRIPTORS:
14. METEORCLOGY - SYNOPTIC STUDIES
15. METEORCLOGY - RAW DATA
17. METEORCLOGY -STATISTICAL STUDIES

48. AUTHORS: FINGER,F. G.
TEWELES,S. , MASON,R. B.
□ SYNOPTIC ANALYSIS BASED ON METEOROLOGICAL ROCKETSONDE DATA
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 68,NO.5,PP 1377-1399
DATE: 1 MARCH 1963 23PP
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DESCRIPTORS:
14. METEORCLOGY - SYNOPTIC STUDIES

263. AUTHORS: FINGER,F. G.
HARRIS,M. F. , TEWELES,S.
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SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 4, NO. 5, PP 632-635
DATE: OCTOBER 1965 4PP
DDC OR NASA NO.

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SOURCE: MONTHLY WEATHER REVIEW
REPORT NUMBER/DESCRIPTION: VOL. 91, NO. 5, PP 191-205
DATE: MAY 1963 15PP
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DESCRIPTORS:
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16. METEORCLOGY - STRATO WARMINGS
18. METEORCLOGY SUMMARY STUDIES

349. AUTHORS: FINGER,F. G.
MASON,R. B. , TEWELES,S.
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REPORTED BY THE U.S. WEATHER BUREAU OUTRIGGER RADIOSONDE
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REPORT NUMBER/DESCRIPTION: VOL. 92, NO. 5, PP 243-250
DATE: MAY 1964 8PP
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PROGRAM FORMULATION
SOURCE: RAYTHEON COMPANY
REPORT NUMBER/DESCRIPTION: AFAL-TR-65-176
DATE: 30 JULY 1965 93PP
DDC CR NASA NO. 467431

DESCRIPTORS:
7. HORIZON SENSORS
8. ATT MEASMT (EXCL HORIZON SENSRS)
9. ATTITUDE CONTROL
21. DATA REDUCTION

204. AUTHORS: FOWLER,R. Z.
ATTITUDE CONTROL STUDY FOR NIMBUS METEOROLOGICAL SATELLITES
SOURCE: ITHACO, INC.
REPORT NUMBER/DESCRIPTION: MONTHLY REPORT NO. 17
DATE: 20 SEPTEMBER 1965 24PP
DDC CR NASA NO. X66-10819
CONTRACT NUMBER NAS 5-3696
DESCRIPTORS:
7. HORIZON SENSORS

205. AUTHORS: FOWLER,R. Z.
ATTITUDE CONTROL STUDY FOR NIMBUS METEOROLOGICAL SATELLITES
SOURCE: ITHACO, INC.
REPORT NUMBER/DESCRIPTION: MONTHLY REPORT NO. 16
DATE: 10 AUGUST 1965 18PP
DDC CR NASA NO. X66-10818
CONTRACT NUMBER NAS 5-3696
DESCRIPTORS:
7. HORIZON SENSORS

206. AUTHORS: FOWLER,R. Z.
ATTITUDE CONTROL SYSTEM FOR NIMBUS METEOROLOGICAL SATELLITES
SOURCE: ITHACO, INC.
REPORT NUMBER/DESCRIPTION: MONTHLY REPORT NO. 18
DATE: 8 OCTOBER 1965 24PP
DDC CR NASA NO. X66-10824
CONTRACT NUMBER NAS 5-3696
DESCRIPTORS:
7. HORIZON SENSORS

377. AUTHORS: FOWLER,R. Z.
ATTITUDE CONTROL STUDY FOR NIMBUS METEOROLOGICAL SATELLITES
SOURCE: ITHACO, INC.
REPORT NUMBER/DESCRIPTION: MONTHLY REPORT NO. 13
DATE: 10 MAY 1965 31PP
DDC CR NASA NO. X65-18670
CONTRACT NUMBER NAS 5-3696
DESCRIPTORS:
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KRIEGSMAN,B. , NESLINE JR.,F. W.
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SOURCE: AIAA JOURNAL
REPORT NUMBER/DESCRIPTION: VOL.1,NO.9,PP 2310-2316
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REPORT NUMBER/DESCRIPTION: VOL.21,NO.2,PP 141-151
DATE: MARCH 1964 11
DDC OR NASA NO.

DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
14. METEOROLOGY - SYNOPTIC STUDIES

383. AUTHORS: GEOPHYSICS RESEARCH DIRECTORATE
□ HANDBOOK OF GEOPHYSICS
SOURCE: CAMBRIDGE RESEARCH CENTER (AIR FORCE)
REPORT NUMBER/DESCRIPTION: REVISED EDITION
DATE: 1960 656PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
14. METEOROLOGY - SYNOPTIC STUDIES
15. METEOROLOGY - RAW DATA
16. METEOROLOGY - STRATO WARMINGS
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18. METEOROLOGY SUMMARY STUDIES

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DATE: MARCH 1965 10PP
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DESCRIPTORS:
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258. AUTHORS: GERGEN,J. L.
□ ATMOSPHERIC INFRARED RADIATION OVER MINNEAPOLIS TO 30 MILLIBARS
SOURCE: METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 14, NO. 6, PP 494-504
DATE: DECEMBER 1957 11PP
DDC OR NASA NO.
CONTRACT NUMBER NONR 710(01)
DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

278. AUTHORS: GERGEN,J. L.
HUCH,W. F. ,
□ SYNOPTIC STUDY OF INFRA-RED RADIATION OVER THE UNITED STATES
SOURCE: NATURE
REPORT NUMBER/DESCRIPTION: VOL. 186, NO. 4723, PP 426-429
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DESCRIPTORS:
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SOURCE: AMERICAN METEOROLOGICAL SOCIETY BULLETIN
REPORT NUMBER/DESCRIPTION: VOL.45,NO. 7,PP 382-387
DATE: JULY 1964 06PP
DDC OR NASA NO.

DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

54. AUTHORS: GLAHN.H. R.
ELLIS.J. O.
NOTES ON THE DETERMINATION OF PROBABILITY ESTIMATES
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL.3, PP 647-650
DATE: OCTOBER 1964 04PP
DDC OR NASA NO.

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES

59. AUTHORS: GODDARD SPACE FLIGHT CENTER
SATELLITE TRACKING AND DATA ACQUISITION NETWORK FACILITIES REPORT (STADAN)
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: X-530-64-159
DATE: JUNE 1964 130PP
DDC OR NASA NO.

DESCRIPTORS:
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13. MISSION PROFILE

273. AUTHORS: GODDARD SPACE FLIGHT CENTER
AVAILABILITY OF RADIATION DATA FROM THE TIROS II, III, IV, AND VII SATELLITES
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: N65-29498
DATE: 2PP
DDC OR NASA NO. TMX-54741

DESCRIPTORS:
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60. AUTHORS: GOETZE.D.
GROSCH.C. B.
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SOURCE: AEROSPACE SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL.29,NO.5,PP 521-524
DATE: MAY 1962 04PP
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DESCRIPTORS:
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61. AUTHORS: GOLDSHLAK.L.
WIDGER JR.,W. K.
NIMBUS II DATA CODE EXPERIMENT
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: 9G26-2
DATE: JANUARY 1966 60PP
DDC OR NASA NO.
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DESCRIPTORS:
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20. DATA HANDLING

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□CYCLOGENESIS AND THE RELATED CLOUD DISTRIBUTION AND STRUCTURE
□OVER THE GULF OF MEXICO - A CASE STUDY
SOURCE: TEXAS A+M UNIVERSITY
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DATE: AUGUST 1964 49PP
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315. AUTHORS: GRAY,D. E.(EDITED BY)
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□ INFRARED INSTRUMENTATION IN SPACE EXPLORATION: INTRODUCTORY
□REPORT
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DDC OR NASA NO. 602936
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DESCRIPTORS:
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7. HORIZON SENSORS

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WEXLER,R. , BOWLEY,C. J.
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□SATELLITE INFRARED DATA
SOURCE: ARACON GEOPHYSICS CO.
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DDC OR NASA NO.
CONTRACT NUMBER NASW-1157
DESCRIPTORS:
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5. RADIANCE (EXPERIMENTAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

178. AUTHORS: GRIEP,D. J.
□ ELECTRONICS RESEARCH PROGRAM-SATELLITE ATTITUDE CONTROL SYSTEM
□EXPERIMENTS
SOURCE: AEROSPACE CORP.
REPORT NUMBER/DESCRIPTION: TDR-269(4250-32)-3
DATE: 1 JANUARY-30 JUNE,1964 76PP
DDC OR NASA NO.
CONTRACT NUMBER AF 04(695)-269
DESCRIPTORS:
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8. ATT MEASMT (EXCL HORIZON SENSORS)
9. ATTITUDE CONTROL

389. AUTHORS: GRIFFITH,W.
□ VIBRATIONAL RELAXATION TIMES IN GASES
SOURCE: APPLIED PHYSICS JOURNAL
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SOURCE: SPACE RESEARCH IV
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SOURCE: GRUMMAN AIRCRAFT ENG. CORP.
REPORT NUMBER/DESCRIPTION: 378C-1
DATE: 28 MARCH 1966 67PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 9-4983
DESCRIPTORS:
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19. LAUNCH VEHICLES AND FACILITIES

227. AUTHORS: GUBAREFF,G. G.
JANSSEN,J. E. , TORBORG,R. H.
□ THERMAL RADIATION PROPERTIES SURVEY
SOURCE: HONEYWELL RESEARCH CENTER
REPORT NUMBER/DESCRIPTION:
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DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

336. AUTHORS: GUSHCHIN,G. P.
SHATUNOV,I. A. ,
□ ATMOSPHERIC OZONE AND JET STREAMS
SOURCE: U. S. DEPARTMENT OF COMMERCE
REPORT NUMBER/DESCRIPTION: TT-65-30052
DATE: 6 JANUARY 1965 19PP
DDC OR NASA NO. N65-13848

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64. AUTHORS: HALE,J. R.
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REPORT NUMBER/DESCRIPTION: F-1843
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SABATINI,R. R. , SISSALA,J. E.
NOVOTNY,L. ,
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REPORT NUMBER/DESCRIPTION: 9G23-F
DATE: DECEMBER 1965 129PP
DDC OR NASA NO.
CONTRACT NUMBER NAS5-9664
DESCRIPTORS:
20. DATA HANDLING
21. DATA REDUCTION

65. AUTHORS: HANEL,R. A.
BANDEEN,W. R. , CONRATH,B. J.
¤ INFRARED HORIZON OF THE PLANET EARTH
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
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218. AUTHORS: HANEL,R. A.
BANDEEN,W. R. , CONRATH,B. J.
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SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION:
DATE: SEPTEMBER 1963 21PP
DDC OR NASA NO. TN D-1850

DESCRIPTORS:
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296. AUTHORS: HARAGAN,D. R.
WAGNER,N. K. , GERHARDT,J. R.
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¤QUARTERLY TECHNICAL REPORT NO. 6
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 OCTOBER 1961-31 DECEMBER 1961 61PP
DDC OR NASA NO. 479082
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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WAGNER,N. K. , GERHARDT,J. R.
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¤QUARTERLY TECHNICAL REPORT NO. 6
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CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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301. AUTHORS: HARAGAN,D. R.
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SOURCE: UNIVERSITY OF TEXAS
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DATE: 1 JANUARY 1963-31 MARCH 1963 32PP
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DESCRIPTORS:
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302. AUTHORS: HARAGAN,D. R.
STEPHENS,J. J. , JEHN,K. H.
□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM -
□QUARTERLY TECHNICAL REPORT NO. 15
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DESCRIPTORS:
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KOWALIK,V. C. ,
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CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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308. AUTHORS: HARAGAN,D. R.
STEPHENS,J. J. , JEHN,K. H.
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CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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340. AUTHORS: HARE,F. K.(CHAIRMAN)
□ SEMINARS ON THE STRATOSPHERE AND MESOSPHERE AND POLAR
□METEOROLOGY
SOURCE: CAMBRIDGE RESEARCH LABORATORIES(AIR FORCE)
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DDC OR NASA NO. 600664
CONTRACT NUMBER AF 19(604)-8431
DESCRIPTORS:
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14. METEORCLOGY - SYNOPTIC STUDIES
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GERMANN JR., E. F. ,
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¤ORIENTATION CONTROL SYSTEMS
SOURCE: NASA
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DDC OR NASA NO. TN-D-1005

DESCRIPTORS:
7. HORIZON SENSORS

203. AUTHORS: HATCHER,N. M.
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¤FOR USE IN SPACECRAFT ATTITUDE DETERMINATION
SOURCE: LANGLEY RESEARCH CENTER
REPORT NUMBER/DESCRIPTION:
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DDC OR NASA NO. TN D-2995

DESCRIPTORS:
7. HORIZON SENSORS
9. ATTITUDE CONTROL

207. AUTHORS: HAVENS,R. J.
KOLL,R. T. , LAGOW,H. E.
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¤TO 160 KILOMETERS
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
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69. AUTHORS: HAYNIE,W. H.
COLLINGE,J. P. , ERTSGAARD,F. P.
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SOURCE: PROCEDURES IRIS
REPORT NUMBER/DESCRIPTION: VOL.8 NO.3,PP 27-33
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□ GEOGRAPHICAL VARIATIONS OF WIND LOADS ON VERTICALLY RISING
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SOURCE: APPLIED METEOROLOGY JOURNAL
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PERSKY,M. J. , LAVERY,A. L.
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SOURCE: CAMBRIDGE RESEARCH LAB. - AIR FORCE
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DATE: 31 JUNE 1963
DDC OR NASA NO.
CONTRACT NUMBER AF 19(628)-1618
DESCRIPTORS:
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7. HORIZON SENSORS

362. AUTHORS: HERING,W. S.
□ OZONESONDE OBSERVATIONS OVER NORTH AMERICA - VOLUME 1
SOURCE: CAMBRIDGE RESEARCH LABORATORIES(AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL-64-30(1)
DATE: JANUARY 1964 512PP
DDC OR NASA NO. 435873

DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

244. AUTHORS: HERING,W. S.(EDITED BY)
BORDEN,JR.,T. R.(EDITED BY) ,
□ OZONESONDE OBSERVATIONS OVER NORTH AMERICA-VOL. 2
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL-64-30(II)
DATE: JULY 1964 282PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
15. METEOROLOGY - RAW DATA

245. AUTHORS: HERING,W. S.(EDITED BY)
BORDEN,JR.,T. R.(EDITED BY) ,
□ OZONESONDE OBSERVATIONS OVER NORTH AMERICA-VOL. 3
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL-64-30(III)
DATE: AUGUST 1965 270PP
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DESCRIPTORS:
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15. METEOROLOGY - RAW DATA

387. AUTHORS: HERZFELD,K. F.
LITOVITZ,T. A. ,
□ ABSORPTION AND DISPERSION OF ULTRASONIC WAVES
SOURCE: ACADEMIC PRESS, NEW YORK AND LONDON
REPORT NUMBER/DESCRIPTION:
DATE: 1959 535
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

108. AUTHORS: HIEATT,J. L.
HAGEN,W. B.
□ RELIABLE EARTH SENSOR
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 205-215
DATE: 1965 11PP
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DESCRIPTORS:
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381. AUTHORS: HILLEARY,D. T.
HEACOCK,E. L. , MORGAN,W. A.
MOORE,R. H. , MANGOLD,E. C.
SCULES,S. D. ,
□ INDIRECT MEASUREMENTS OF ATMOSPHERIC TEMPERATURE PROFILES FROM
□SATELLITES: III. THE SPECTROMETERS AND EXPERIMENTS
SOURCE: MONTHLY WEATHER REVIEW
REPORT NUMBER/DESCRIPTION: VOL. 94, NO. 6, PP 367-377
DATE: JUNE 1966 11PP
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DESCRIPTORS:
6. RADIOMETERS

190. AUTHORS: HONEYWELL, INC.
□ HORIZON DEFINITION MEASUREMENT PROGRAM - TECHNICAL PROPOSAL
SOURCE: HONEYWELL, INC.
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DATE: 15 OCTOBER 1965
DDC OR NASA NO.

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9. ATTITUDE CONTROL
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11. TRACKING AND DATA ACQUISITION
12. SPACECRAFT POWER SYSTEMS
13. MISSION PROFILE
18. METEOROLOGY SUMMARY STUDIES
19. LAUNCH VEHICLES AND FACILITIES
20. DATA HANDLING

195. AUTHORS: HONEYWELL, INC.
□ HORIZON DEFINITION MEASUREMENT PROGRAM - PRESENTATION
SOURCE: HONEYWELL, INC.
REPORT NUMBER/DESCRIPTION: S6R-2
DATE: JANUARY 1966 30PP
DDC OR NASA NO.

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11. TRACKING AND DATA ACQUISITION
12. SPACECRAFT POWER SYSTEMS
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20. DATA HANDLING

231. AUTHORS: HONEYWELL, INC.
□ LOCAL VERTICAL PREDICTION SYSTEM STUDY - A PROPOSAL
SOURCE: HONEYWELL AERONAUTICAL DIVISION - BOSTON
REPORT NUMBER/DESCRIPTION: 4402-007
DATE: 27 MARCH 1964 82PP
DDC OR NASA NO.

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8. ATT MEASMT (EXCL HORIZON SENSORS)
9. ATTITUDE CONTROL

316. AUTHORS: HONEYWELL, INC.
¤ SCANNER SPACECRAFT - VOLUME I. TECHNICAL PROPOSAL
SOURCE: HONEYWELL, INC.
REPORT NUMBER/DESCRIPTION: 3E-B-34
DATE: 5 DECEMBER 1963 122PP
DDC CR NASA NO.

DESCRIPTORS:
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10. SPACECRAFT STRUCTURE
12. SPACECRAFT POWER SYSTEMS
20. DATA HANDLING

72. AUTHORS: HOPKINS JR., M. N.
SMITH, R. B.
¤ SUMMARY OF TECHNICAL SERVICES PROVIDED TO NIMBUS DATA
¤UTILIZATION CENTER
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: 237-F
DATE: DECEMBER 1965 59PP
DDC CR NASA NO.
CONTRACT NUMBER NAS5-3253
DESCRIPTORS:
21. DATA REDUCTION

99. AUTHORS: HORAN, J. J.
¤ PERFORMANCE AND SYSTEMS APPLICATIONS OF HORIZON SENSORS ON
¤SPIN-STABILIZED SPACECRAFT
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 89-100
DATE: 1965 12PP
DDC CR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS
9. ATTITUDE CONTROL

289. AUTHORS: HORAN, J. J.
GORDON, F. , DWORK, M.
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SOURCE: PROCEEDINGS OF THE INFRARED INFORMATION SYMPOSIUM
REPORT NUMBER/DESCRIPTION: PP 9-21
DATE: JUNE 1965 13PP
DDC CR NASA NO. NAVSO P-2315

DESCRIPTORS:
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9. ATTITUDE CONTROL

251. AUTHORS: HOUGHTON, J. T.
SHAW, J. H.
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¤OBSERVATIONS OF EMISSION BY THE 15 MICRON CO(2) BAND
SOURCE: INFRARED SPECTRA OF ASTRONOMICAL BODIES
REPORT NUMBER/DESCRIPTION: PP 350-356
DATE: 24-25-26 JUNE 1963 7PP
DDC CR NASA NO. 602936
CONTRACT NUMBER AF 61(052)-685
DESCRIPTORS:
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2. RADIANCE (THEORETICAL 15 U)
6. RADIOMETERS

253. AUTHORS: HOWARD,J. N.
GARING,J. S.
□ INFRARED TELLURIC ABSORPTION SPECTRUM INTRODUCTORY REPORT
SOURCE: INFRARED SPECTRA OF ASTRONOMICAL BODIES
REPORT NUMBER/DESCRIPTION: PP 237-278
DATE: 24-25-26 JUNE 1963 42PP
DDC OR NASA NO. 602936
CONTRACT NUMBER AF 61(052)-685
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3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

378. AUTHORS: HUNT,B. G.
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□ATOMIC OXYGEN AND OZONE VARIATIONS IN THE MESOSPHERE
SOURCE: AUSTRALIAN DEFENCE SCIENTIFIC SERVICE
REPORT NUMBER/DESCRIPTION: TN PAD 82
DATE: FEBRUARY 1964
DDC OR NASA NO. N64-19473

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

92. AUTHORS: HURTT,J. E.
FRANCIS,R. N.
□ PROJECT HYDRA-IRIS
SOURCE: U.S. NAVAL ORDNANCE TEST STATION
REPORT NUMBER/DESCRIPTION: NOTS 3391
DATE: FEBRUARY 1965 18PP
DDC OR NASA NO. 431792

DESCRIPTORS:
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19. LAUNCH VEHICLES AND FACILITIES
20. DATA HANDLING

357. AUTHORS: JACKSON,B. S.
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□DISTRIBUTION, METHODS OF DETECTION, AND RELATIONSHIP WITH OTHER
□METEOROLOGICAL PHENOMENA
SOURCE: UNIVERSITY OF CALIFORNIA
REPORT NUMBER/DESCRIPTION: LA-3328-MS
DATE: 15 JULY 1965 36PP
DDC OR NASA NO. N65-29012
CONTRACT NUMBER W-7405-ENG.36
DESCRIPTORS:
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291. AUTHORS: JALINK,JR.,A.
□ INVESTIGATION OF THE EARTHS HORIZON IN THE INFRARED
SOURCE: UNIVERSITY OF VIRGINIA
REPORT NUMBER/DESCRIPTION: MASTERS THESIS
DATE: JUNE 1966 70PP
DDC OR NASA NO.

DESCRIPTORS:
4. RADIANCE (EXPERIMENTAL 15 U)
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS

268. AUTHORS: JEHN,K. H.
WAGNER,N. K. , GERHARDT,J. R.
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¤QUARTERLY TECHNICAL REPORT NO. 1
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JULY 1960-30 SEPTEMBER 1960 56PP
DDC OR NASA NO. 479078
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

269. AUTHORS: JEHN,K. H.
WAGNER,N. K. , GERHARDT,J. R.
HARAGAN,D. R. ,
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REPORT NUMBER/DESCRIPTION:
DATE: 1 OCTOBER 1960-31 DECEMBER 1960 30PP
DDC OR NASA NO. 479079
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

309. AUTHORS: JEHN,K. H.
HARAGAN,D. R. , STEPHENS,J. J.
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SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 OCTOBER 1963-31 DECEMBER 1963 22PP
DDC OR NASA NO. 479090
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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73. AUTHORS: JOHNSON,F. S.
¤ ATMOSPHERE AND NEAR SPACE
SOURCE: ASTRONAUTICS AND AEROSPACE ENGINEERING
REPORT NUMBER/DESCRIPTION: VOL. 1, PP 81-87
DATE: NOVEMBER 1963 07PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

232. AUTHORS: JOHNSON,F. S.
¤ ATMOSPHERIC STRUCTURE
SOURCE: ASTRONAUTICS
REPORT NUMBER/DESCRIPTION: VOL. 7, NO. 1, PP 54-61
DATE: AUGUST 1962 08PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

221. AUTHORS: JONES,D. E.
¤ MARINER II MICROWAVE RADIOMETER EXPERIMENT
SOURCE: JPL
REPORT NUMBER/DESCRIPTION: 32-722
DATE: 1 JANUARY 1966 57PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 7-100
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS

74. AUTHORS: JONES,L. M.
¤ UPPER AIR STRUCTURE MEASUREMENTS WITH SMALL ROCKETS
SOURCE: SPACE RESEARCH II
REPORT NUMBER/DESCRIPTION:
DATE: 1961 12PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES

209. AUTHORS: JONES,L. M.
PETERSON,J. W. , SCHAEFER,E. J.
SCHULTE,H. F. ,
¤ UPPER-AIR DENSITY AND TEMPERATURE: SOME VARIATIONS AND AN
¤ABRUPT WARMING IN THE MESOSPHERE
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 64, NO. 12,PP 2331-2340
DATE: DECEMBER 1959 10PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
16. METEOROLOGY - STRATO WARMINGS
18. METEOROLOGY SUMMARY STUDIES

214. AUTHORS: JONES,R. C.
¤ STUDY OF IR BACKGROUNDS BY THE WIENER SPECTRUM METHOD
SOURCE: POLAROID CORP.
REPORT NUMBER/DESCRIPTION:
DATE: DECEMBER 1959 185PP
DDC OR NASA NO.
CONTRACT NUMBER AF 33(616)5550
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

219. AUTHORS: JONES,R. L.
¤ THEORETICAL METHOD FOR DERIVING AN EARTH-CENTERED DATUM FROM
¤OPTICAL OBSERVATIONS OF THE EARTHS HORIZON FROM AN EARTH
¤SATELLITE
SOURCE: LANGLEY RESEARCH CENTER
REPORT NUMBER/DESCRIPTION: L-4718
DATE: APRIL 1966 60PP
DDC OR NASA NO. TN D-3367

DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
8. ATT MEASMT (EXCL HORIZON SENSORS)
21. DATA REDUCTION

75. AUTHORS: JONES,W. T.
WARD,K. A. ,
¤ PERFORMANCE OF HORIZON SENSOR SYSTEMS IN EARTH ORBIT
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION:
DATE: 1965 16PP
DDC OR NASA NO.

DESCRIPTORS:
4. RADIANCE (EXPERIMENTAL 15 U)
5. RADIANCE (EXPERIMENTAL OTHER)
7. HORIZON SENSORS

106. AUTHORS: KALLET,E. A.
¤ RADIATION BALANCE HORIZON SENSORS
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 175-193
DATE: 1965 19PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS

76. AUTHORS: KANTOR, A. J.
COLE, A. E.
□ ZONAL AND MERIDIONAL WINDS TO 170 KILOMETERS
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 69, NO. 24, PP 5131-5140
DATE: 15 DECEMBER 1964 10PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

432. AUTHORS: KANTOR, A. J.
COLE, A. E.
□ MONTHLY ATMOSPHERIC STRUCTURE, SURFACE TO 80 KILOMETERS
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 4, NO. 2, PP 228-237
DATE: APRIL 1965 10PP
DDC OR NASA NO.

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

325. AUTHORS: KANWISHER, J.
□ PCO(2) IN SEA WATER AND ITS EFFECT ON THE MOVEMENT OF CO(2)
□IN NATURE
SOURCE: TELLUS
REPORT NUMBER/DESCRIPTION: VOL. 12, NO.2, PP 209-215
DATE: MAY 1960 7PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

257. AUTHORS: KAPLAN, L. D.
EGGERS JR., D. F
□ INTENSITY AND LINE-WIDTH OF THE 15-MICRON CO(2) BAND,
□DETERMINED BY A CURVE-OF-GROWTH METHOD
SOURCE: CHEMICAL PHYSICS JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 25, NO. 5, PP 876-883
DATE: NOVEMBER 1956 8PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
18. METEOROLOGY SUMMARY STUDIES

329. AUTHORS: KAPLAN, L. D.
□ INFLUENCE OF CARBON DIOXIDE VARIATIONS ON THE ATMOSPHERIC
□HEAT BALANCE
SOURCE: TELLUS
REPORT NUMBER/DESCRIPTION: VOL. 12, NO. 2, PP 204-208
DATE: MAY 1960 5PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

192. AUTHORS: KAUTH, R. J.
□ MULTICOLOR ATMOSPHERIC MODELS
SOURCE: UNIVERSITY OF CHICAGO
REPORT NUMBER/DESCRIPTION: IAS-TR-199-49
DATE: SEPTEMBER 1963 11PP
DDC OR NASA NO. 419045
CONTRACT NUMBER SD-71
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)
17. METEOROLOGY -STATISTICAL STUDIES

77. AUTHORS: KEELING,C. D.
RAKESTRAW,N. W. , WATERMAN,L. S.
□ CARBON DIOXIDE IN SURFACE WATERS OF THE PACIFIC OCEAN -
□1. MEASUREMENTS OF THE DISTRIBUTION
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 70, NO. 24,PP 6087-6097
DATE: 15 DECEMBER 1965 11PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES

78. AUTHORS: KEELING,C. D.
□ CARBON DIOXIDE IN SURFACE WATERS OF THE PACIFIC OCEAN
□2. CALCULATION OF THE EXCHANGE WITH THE ATMOSPHERE
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 70, NO. 24,PP 6099-6102
DATE: 15 DECEMBER 1965 04PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES

327. AUTHORS: KEELING,C. D.
□ CONCENTRATION AND ISOTOPIC ABUNDANCES OF CARBON DIOXIDE IN
□THE ATMOSPHERE
SOURCE: TELLUS
REPORT NUMBER/DESCRIPTION: VOL. 12, NO. 2, PP 200-203
DATE: MAY 1960 4PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

216. AUTHORS: KERN,C. D.
□ EVALUATION OF INFRARED EMISSION OF CLOUDS AND GROUND AS
□MEASURED BY WEATHER SATELLITES
SOURCE: CAMBRIDGE RESEARCH LAB.(AF)
REPORT NUMBER/DESCRIPTION: AFCRL-65-840
DATE: NOVEMBER 1965 112PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
4. RADIANCE (EXPERIMENTAL 15 U)
5. RADIANCE (EXPERIMENTAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

110. AUTHORS: KERR,D. E.(EDITED BY)
□ PROPAGATION OF SHORT RADIO WAVES
SOURCE: MCGRAW-HILL
REPORT NUMBER/DESCRIPTION: MIT RAD.LAB.SER.,VOL.13,PP 41-50
DATE: 1958 10PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

79. AUTHORS: KING,J. I. F.
□ INVERSION BY SLABS OF VARYING THICKNESS
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 21,PP 324-326
DATE: MAY 1964 03PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

91. AUTHORS: KING,J. I. F.
□ REPLY
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 22, P 96
DATE: JANUARY 1965 01PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
8. ATT MEASMT (EXCL HORIZON SENSRS)

337. AUTHORS: KISS,E.
□ BIBLIOGRAPHY ON METEOROLOGICAL SATELLITES (1952-1962)
SOURCE: AMERICAN METEOROLOGICAL SOCIETY
REPORT NUMBER/DESCRIPTION:
DATE: APRIL 1963 399PP
DDC OR NASA NO. N64-14260

DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS
14. METEOROLOGY - SYNOPTIC STUDIES
15. METEOROLOGY - RAW DATA
16. METEOROLOGY - STRATO WARMINGS
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

81. AUTHORS: KNOLL,A. L.
EDELSTEIN,M. M.
□ ESTIMATION OF LOCAL VERTICAL AND ORBITAL PARAMETERS FOR AN
□EARTH SATELLITE ON THE BASIS OF HORIZON SENSOR MEASUREMENTS
SOURCE: HONEYWELL, INC.
REPORT NUMBER/DESCRIPTION.
DATE: 20 JANUARY 1964 41PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS
9. ATTITUDE CONTROL

82. AUTHORS: KOCHANSKI,A.
□ CIRCULATION AND TEMPERATURES AT 70- TO 100-KILOMETER HEIGHT
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 68, NO.1,PP 213-226
DATE: 1 JANUARY 1963 14PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES

83. AUTHORS: KOLOSOV,S. G.
□ CONNEXION BETWEEN THE TEMPERATURE FIELD AND THE FIELD OF
□OUTGOING RADIATION FROM THE EARTH AND THE TROPOSPHERE
SOURCE: PLANET. SPACE SCIENCES
REPORT NUMBER/DESCRIPTION: VOL. 11,PP 987-993
DATE: 1963 07PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)

84. AUTHORS: KONDRATIEV,K. Y.
YAKUSHEVSKAYA,K. E.
□ ANGULAR DISTRIBUTION OF THE OUTGOING THERMAL RADIATION IN THE
□ DIFFERENT REGIONS OF THE SPECTRUM
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: 620.1333P T8.I,PP 254-277
DATE: 1962 24PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)

94. AUTHORS: KONDRATIEV,K. Y.
GAYEVSKAYA,G. N., NIKOLSKIY,G. A.
SOLONIN,S. V., LIBERMAN,Y. W.
SHVED,G. M., TSARITSYNA,I. V.
□ PROBLEMS OF THE PHYSICS OF THE ATMOSPHERE-COLLECTION I
SOURCE: LENINGRAD UNIVERSITY PRESS
REPORT NUMBER/DESCRIPTION:
DATE: 1963 169PP
DDC OR NASA NO. TT F-184

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

134. AUTHORS: KONDRATIEV,K. Y.
YAKUSHEVSKAYA,K. Y.
□ SPECTRAL DISTRIBUTION OF OUTGOING RADIATION
SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: 1963 21PP
DDC OR NASA NO. TT F-210

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

184. AUTHORS: KONDRATIEV,K. Y.
□ ACTINOMETRY
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-9712
DATE: NOVEMBER 1965 675PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
5. RADIANCE (EXPERIMENTAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

185. AUTHORS: KONDRATIEV,K. Y.
□ ABSORPTION OF ATMOSPHERIC THERMAL RADIATION IN THE 9.6 MICRON
□ OZONE BAND REGION
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-207
DATE: JUNE 1964 27PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

186. AUTHORS: KONDRATIEV,K. Y.
□ INFRARED ABSORPTION SPECTRUM OF WATER IN ITS LIQUID STATE
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-211
DATE: JULY 1964 27 PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

187. AUTHORS: KONDRATIEV,K. Y.
□ INVESTIGATING THE SPECTRAL DISTRIBUTION OF SHORTWAVE RADIATION
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-213
DATE: JULY 1964 20PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

188. AUTHORS: KONDRATIEV,K. Y.
□ METEOROLOGICAL INVESTIGATIONS WITH ROCKET AND SATELLITES
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-115
DATE: SEPTEMBER 1963 284PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

189. AUTHORS: KONDRATIEV,K. Y.
□ METEOROLOGICAL SATELLITES
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-177
DATE: MAY 1964 288PP
DDC OR NASA NO.

DESCRIPTORS:
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
4. RADIANCE (EXPERIMENTAL 15 U)
5. RADIANCE (EXPERIMENTAL OTHER)
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

191. AUTHORS: KONDRATIEV,K. Y.
□ THERMAL RADIATION OF CO(2) IN THE ATMOSPHERE
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TT-F-206
DATE: JULY 1964 21PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
18. METEOROLOGY SUMMARY STUDIES

348. AUTHORS: KONDRATIEV,K. Y.
□ OUTGOING RADIATION AND THE RADIANT HEAT FLUX
SOURCE: METEOROLOGY AND HYDROLOGY
REPORT NUMBER/DESCRIPTION: NO. 11, PP 57-61
DATE: 1965 5PP
DDC OR NASA NO. N66-15457

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)

417. AUTHORS: KONDRATIEV,K. Y.
¤ SOME PROBLEMS ASSOCIATED WITH THE INTERPRETATION OF THE RESULTS
¤OF MEASURING THE OUTGOING RADIATION BY MEANS OF METEOROLOGICAL
¤SATELLITES
SOURCE: LENINGRAD STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: NASA TT F-8563
DATE: OCTOBER 1965 20PP
DDC OR NASA NO. N64-23118

DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
5. RADIANCE (EXPERIMENTAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

415. AUTHORS: KONDRAU,O. D.
¤ QUESTION OF THE DAILY VARIATION OF CLOUDINESS IN THE SOVIET
¤UNION
SOURCE: AIR FORCE SYSTEMS COMMAND
REPORT NUMBER/DESCRIPTION: FTD-TT-63-1205/1+2+4
DATE: 28 APRIL 1964 15PP
DDC OR NASA NO. 600525

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

85. AUTHORS: KOZEL,S. M.
¤ ABOUT A CERTAIN METHOD OF RECORDING WEAK INFRARED RADIATION
SOURCE: AIR FORCE SYSTEMS COMMAND
REPORT NUMBER/DESCRIPTION: FTD-TT-63-180/1+2
DATE: 16 MAY 1963 06PP
DDC OR NASA NO.

DESCRIPTORS:
6. RADIOMETERS

233. AUTHORS: KREITZBERG,C. W.
BROCKMAN,W. E.
¤ COMPUTER PROCESSING OF MESOSCALE RAWINSONDE DATA FROM PROJECT
¤STORMY SPRING
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL-66-97
DATE: FEBRUARY 1966 98PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
14. METEOROLOGY - SYNOPTIC STUDIES

107. AUTHORS: KRUSE JR.,J. R.
¤ RADIANCE COMPENSATING HORIZON SENSOR
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 195-203
DATE: 1965 9PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS

267. AUTHORS: KUHN,K. H.
STARK,E. W.
¤ HORIZON TRACKERS FOR LUNAR GUIDANCE AND CONTROL SYSTEMS
SOURCE: LUNAR EXPLORATION AND SPACECRAFT SYSTEMS
REPORT NUMBER/DESCRIPTION: PP 108-152
DATE: 1962 45PP
DDC OR NASA NO.
CONTRACT NUMBER AF 33(616)-6674
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
7. HORIZON SENSORS

284. AUTHORS: KUZNETSOV, A. P.
□ OBSERVATIONS OF THE VERTICAL DISTRIBUTION OF OZONE IN THE
□ATMOSPHERE
SOURCE: BULLETIN OF THE ACADEMY OF SCIENCES OF THE U.S.S.R.
REPORT NUMBER/DESCRIPTION: NO. 9, PP 91-100
DATE: 1957 10PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

355. AUTHORS: KYLE, T. G.
MURCRAY, D. G. , MURCRAY, F. H.
WILLIAMS, W. J. ,
□ ABSORPTION OF SOLAR RADIATION BY ATMOSPHERIC CARBON DIOXIDE
SOURCE: OPTICAL SOCIETY OF AMERICA JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 55, NO. 11, PP 1421-1426
DATE: NOVEMBER 1965 6PP
DDC OR NASA NO.

DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
5. RADIANCE (EXPERIMENTAL OTHER)

313. AUTHORS: LABITZKE, K.
□ MUTUAL RELATION BETWEEN STRATOSPHERE AND TROPOSPHERE DURING
□PERIODS OF STRATOSPHERIC WARMINGS IN WINTER
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 4, PP 91-99
DATE: FEBRUARY 1965 9PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
16. METEOROLOGY - STRATO WARMINGS

433. AUTHORS: LABITZKE, K.
VAN LOON, H. ,
□ NOTE ON STRATOSPHERIC MIDWINTER WARMINGS IN THE SOUTHERN
□HEMISPHERE
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 4, NO. 2, PP 292-299
DATE: APRIL 1965 8PP
DDC OR NASA NO.

DESCRIPTORS:
16. METEOROLOGY - STRATO WARMINGS
18. METEOROLOGY SUMMARY STUDIES

86. AUTHORS: LAGOW, H. E.
HOROWITZ, R. , AINSWORTH, J.
□ ROCKET MEASUREMENTS OF THE ARCTIC UPPER ATMOSPHERE
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION:
DATE: 1958 09PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

87. AUTHORS: LAGOW, H. E.
HOROWITZ, R. , AINSWORTH, J.
□ ARCTIC ATMOSPHERIC STRUCTURE TO 250 KM
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION:
DATE: 1958 09PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

420. AUTHORS: LAMBERT,J. D.
¤ RELAXATION IN GASES
SOURCE: ACADEMIC PRESS
REPORT NUMBER/DESCRIPTION: ATOMIC AND MOLECULAR PROCESSES
DATE: 1962 24PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

375. AUTHORS: LANGLEY RESEARCH CENTER
¤ SPECIFICATIONS FOR THE DESIGN, FABRICATION, QUALIFICATION,
¤ENVIRONMENTAL TESTING, AND CALIBRATION OF THE DUAL RADIOMETER
¤ASSEMBLY
SOURCE: LANGLEY RESEARCH CENTER
REPORT NUMBER/DESCRIPTION: I-3771
DATE: 1 NOVEMBER 1963 38PP
DDC OR NASA NO.

DESCRIPTORS:
6. RADIOMETERS

88. AUTHORS: LENHARD JR.,R. W.
COURT,A. , SALMELA,H. A.
¤ VARIABILITY SHOWN BY HOURLY WIND SOUNDINGS
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 2,PP 99-104
DATE: FEBRUARY 1963 06PP
DDC OR NASA NO.

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
17. METEOROLOGY -STATISTICAL STUDIES

212. AUTHORS: LILLESTRAND,R. L.
CARROLL,J. E. ,
¤ HORIZON-BASED SATELLITE NAVIGATION SYSTEMS
SOURCE: IEEE TRANSACTIONS ON AEROSPACE AND NAVIGATION ELECTRONICS
REPORT NUMBER/DESCRIPTION: VOL. ANE-10, NO. 3, PP 247-270
DATE: SEPTEMBER 1963 24PP
DDC OR NASA NO. A64-10467
CONTRACT NUMBER AF 33(657)-8215
DESCRIPTORS:
2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
7. HORIZON SENSORS
8. ATT MEASMT (EXCL HORIZON SENSORS)

222. AUTHORS: LILLESTRAND,R. L.
CARROLL,J. E. , NEWCOMB,J. S.
¤ AUTOMATIC CELESTIAL GUIDANCE, PT. 2: NEW CHALLENGE TO DESIGNERS
¤INGENUITY
SOURCE: ELECTRONICS
REPORT NUMBER/DESCRIPTION:
DATE: 4 APRIL 1966 11PP
DDC OR NASA NO.

DESCRIPTORS:
8. ATT MEASMT (EXCL HORIZON SENSORS)
9. ATTITUDE CONTROL
21. DATA REDUCTION

89. AUTHORS: LINDZEN,R.
GOODY,R. M. ,
¤ RADIATIVE AND PHOTOCHEMICAL PROCESSES IN MESOSPHERIC DYNAMICS:
¤PART I, MODELS FOR RADIATIVE AND PHOTOCHEMICAL PROCESSES
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 22,NO. 4, PP 341-348
DATE: JULY 1965 08PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)

463. AUTHORS: LOCKHEED - CALIFORNIA CO.
¤ SUMMARY OF THE NASA MARKET
SOURCE: LOCKHEED - CALIFORNIA CO.
REPORT NUMBER/DESCRIPTION: CA/MP/94
DATE: 23 AUGUST 1963 27PP
DDC OR NASA NO.

DESCRIPTORS:
13. MISSION PROFILE
19. LAUNCH VEHICLES AND FACILITIES

418. AUTHORS: LONG, M. J.
HANKS, JR., H. H. , BEEBE, R. G.
¤ TROPOPAUSE PENETRATIONS BY CUMULONIMBUS CLOUDS
SOURCE: ATMOSPHERIC RESEARCH AND DEVELOPMENT CORP.
REPORT NUMBER/DESCRIPTION: AFCRL-65-561
DATE: JUNE 1965
DDC OR NASA NO. 621573
CONTRACT NUMBER AF 19(628)-2454
DESCRIPTORS:
14. METEORCLOGY - SYNOPTIC STUDIES
17. METEORCLOGY -STATISTICAL STUDIES

90. AUTHORS: LUNDE, B. K.
¤ HORIZON SENSING FOR ATTITUDE DETERMINATION
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION:
DATE: MARCH 1962 19PP
DDC OR NASA NO.

DESCRIPTORS:
6. RADIOMETERS
7. HORIZON SENSCRS

112. AUTHORS: MACCREADY JR., P. B.
TODD, C. J.
¤ CONTINUOUS PARTICLE SAMPLER
SOURCE: APPLIED METECROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 3, PP 450-460
DATE: AUGUST 1964 11PP
DDC OR NASA NO.

DESCRIPTORS:
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115. AUTHORS: MACCREADY JR., P. B.
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SOURCE: APPLIED METECROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 3, PP 439-449
DATE: AUGUST 1964 11PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEORCLOGY SUMMARY STUDIES

116. AUTHORS: MACHTA, L.
¤ TRANSPORT IN THE STRATOSPHERE AND THROUGH THE TROPOPAUSE
SOURCE: ADVANCES IN GEOPHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 6, PP 273-288
DATE: 1959 16PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

350. AUTHORS: MACLAREN,A. P.
¤ AUTOMATIC CONTROL IN THE PEACEFUL USE OF SPACE-PART 1
SOURCE: CONTROL
REPORT NUMBER/DESCRIPTION: VOL. 9, PP 483-487
DATE: SEPTEMBER 1965 5PP
DDC OR NASA NO.

DESCRIPTORS:
8. ATT MEASMT (EXCL HORIZON SENSRS)
9. ATTITUDE CONTROL

351. AUTHORS: MACLAREN,A. P.
¤ AUTOMATIC CONTROL IN THE PEACEFUL USE OF SPACE-PART 2
SOURCE: CONTROL
REPORT NUMBER/DESCRIPTION: VOL. 9, PP 564-566
DATE: NOVEMBER 1965 3PP
DDC OR NASA NO.

DESCRIPTORS:
8. ATT MEASMT (EXCL HORIZON SENSRS)
9. ATTITUDE CONTROL

352. AUTHORS: MACLAREN,A. P.
¤ AUTOMATIC CONTROL IN THE PEACEFUL USE OF SPACE-PART 3
SOURCE: CONTROL
REPORT NUMBER/DESCRIPTION: VOL. 9, PP 632-635
DATE: NOVEMBER 1965 4PP
DDC OR NASA NO.

DESCRIPTORS:
8. ATT MEASMT (EXCL HORIZON SENSRS)
9. ATTITUDE CONTROL

117. AUTHORS: MAEDA,K.
TAKEYA,Y.
¤ UPPER ATMOSPHERIC TEMPERATURE AND WIND VELOCITY MEASURED BY
¤SOUNDING ROCKETS
SOURCE: SPACE RESEARCH II
REPORT NUMBER/DESCRIPTION: PP 1080-1082
DATE: 1961 03PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

118. AUTHORS: MALKEVICH,M. S.
TATARSKII,V. I.
¤ DETERMINATION OF THE VERTICAL TEMPERATURE PROFILE OF THE
¤ATMOSPHERE FROM THE OUTWARD RADIATION IN THE CO(2) ABSORPTION
¤BAND
SOURCE: COSMIC RESEARCH
REPORT NUMBER/DESCRIPTION: VOL. 3,NO. 3, PP 170-190
DATE: 18 AUGUST 1965 21PP
DDC OR NASA NO. N65-34925

DESCRIPTORS:
2. RADIANCE (THEORETICAL 15 U)
18. METEOROLOGY SUMMARY STUDIES

339. AUTHORS: MALKUS,J. S.
RIEHL,H.
¤ CLOUD STRUCTURE AND DISTRIBUTIONS OVER THE TROPICAL PACIFIC
¤OCEAN
SOURCE: UNIVERSITY OF CALIFORNIA PRESS/BERKELEY AND LOS ANGELES
REPORT NUMBER/DESCRIPTION:
DATE: 1964 229PP
DDC OR NASA NO. A65-15661

DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

344. AUTHORS: MARKOV,M. N.
MERSON,Y. I. , SHAMILEV,M. R.
▫ SEASONAL VARIATIONS OF THE FIELD OF TERRESTRIAL AND ATMOSPHERIC
▫RADIATION IN THE INFRARED REGION OF THE SPECTRUM
SOURCE: COSMIC RESEARCH
REPORT NUMBER/DESCRIPTION: VOL. 3, NO. 2, PP 188-200
DATE: MARCH 1965-APRIL 1965 13PP
DDC OR NASA NO.

DESCRIPTORS:
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414. AUTHORS: MARLATT,W. E.
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▫CHARACTERISTICS OF CLOUD TOPS AND OF THE EARTHS SURFACE
SOURCE: COLORADO STATE UNIVERSITY
REPORT NUMBER/DESCRIPTION: TECH. PAPER NO. 51
DATE: FEBRUARY 1964 92PP
DDC OR NASA NO. N64-29504
CONTRACT NUMBER NASR-147
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

282. AUTHORS: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SECRET ▫ SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT
▫PROGRAM - VOLUME II,PART C. INSTRUMENTATION RESEARCH AND
▫DEVELOPMENT
SOURCE: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
REPORT NUMBER/DESCRIPTION: SSD-TDR-64-63
DATE: 10 JANUARY 1963-10 JANUARY 1964 228PP
DDC OR NASA NO.
CONTRACT NUMBER AF 04(695)-290
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)

374. AUTHORS: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CONF. ▫ SPACE VEHICLE GUIDANCE INVESTIGATIONS EXPLORATORY DEVELOPMENT
▫PROGRAM- FINAL TECHNICAL REPORT: VOLUME II, PART C. CONTROL
▫SYSTEM STUDIES, PART D. INSTRUMENTATION RESEARCH AND DEVELOPMENT
SOURCE: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
REPORT NUMBER/DESCRIPTION: R-473, SSD-TR-64-296
DATE: 10 NOVEMBER 1964 388PP
DDC OR NASA NO. 355186
CONTRACT NUMBER AF 04(695)-290
DESCRIPTORS:
6. RADIOMETERS
7. HORIZON SENSORS
8. ATT MEASMT (EXCL HORIZON SENSRS)
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119. AUTHORS: MASSEY,H. S. W.
▫ PROGRESS OF THE BRITISH UPPER ATMOSPHERIC ROCKET RESEARCH
▫PROGRAMME
SOURCE: INTERNATIONAL GEOPHYSICAL YEAR ANNALS
REPORT NUMBER/DESCRIPTION: VOL. XII,PART 1,PP 36-42
DATE: 1960 07PP
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DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

359. AUTHORS: MAYOT,M.
VIGROUX,E ,
▫ APPLICATION OF CURTIS-GODSONS APPROXIMATION TO THE 9.6 MICRON
▫BAND OF ATMOSPHERIC OZONE
SOURCE: INSTITUTE OF ASTROPHYSICS-PARIS(FRANCE)
REPORT NUMBER/DESCRIPTION: AFCRL-65-265
DATE: 31 JANUARY 1965 52PP
DDC OR NASA NO. 618910
CONTRACT NUMBER AF 61(052)-685
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

120. AUTHORS: MCARTHUR,W. G.
□ HORIZON SENSOR NAVIGATION ERRORS RESULTING FROM STATISTICAL
□VARIATIONS IN THE CO(2) 14-16 MICRON RADIATION BAND
SOURCE: TRANS. ON 9TH SYMP. ON BALLISTIC MISSILE AND SPACE TECHNOLOGY
REPORT NUMBER/DESCRIPTION: VOL. 1,PP 261-289
DATE: AUGUST 1964 29PP
DDC OR NASA NO.

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2. RADIANCE (THEORETICAL 15 U)
4. RADIANCE (EXPERIMENTAL 15 U)
14. METEOROLOGY - SYNOPTIC STUDIES
17. METEOROLOGY -STATISTICAL STUDIES

58. AUTHORS: MCDONALD,R. K.
SECRET □ INFRARED SATELLITE BACKGROUNDS-PART II. BACKGROUND MEASUREMENTS
□EVALUATION
SOURCE: BOEING COMPANY
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DATE: 30 SEPTEMBER 1961 28PP
DDC OR NASA NO. 328365
CONTRACT NUMBER AF 19(604)-7457
DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
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272. AUTHORS: MCGEE,R. A.
□ ANALYTICAL INFRARED RADIATION MODEL OF THE EARTH
SOURCE: APPLIED OPTICS
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DATE: SEPTEMBER 1962 5PP
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DESCRIPTORS:
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WHITMAN,R. I. , ENGLE,C. D.
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SOURCE: LANGLEY RESEARCH CENTER
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DDC OR NASA NO. TN D-2528

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3. RADIANCE (THEORETICAL OTHER)
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS

176. AUTHORS: MEDITCH,J. S.
□ STUDY OF OPTIMAL LINEAR ESTIMATION FOR A HORIZON SCANNER
SOURCE: AEROSPACE CORP.
REPORT NUMBER/DESCRIPTION: TDR-269(4540-70)-7
DATE: 25 AUGUST 1964 22PP
DDC OR NASA NO.
CONTRACT NUMBER AF 04(695)-269
DESCRIPTORS:
7. HORIZON SENSORS

179. AUTHORS: MEDITCH,J. S.
LEMAY,J. L. , JANUS,J. P.
□ ANALYSIS OF AN HORIZON SCANNER AUTONOMOUS ORBITAL NAVIGATION
□SYSTEM
SOURCE: AEROSPACE CORP.
REPORT NUMBER/DESCRIPTION: TDR-469(5540-10)-6
DATE: JULY 1965 61PP
DDC OR NASA NO. 469349
CONTRACT NUMBER AF 04(695)-469
DESCRIPTORS:
7. HORIZON SENSORS
9. ATTITUDE CONTROL

93. AUTHCRS: MERLEN,M. M.
PASTERNAK,J. M. , PEARSALL,D.
¤ ELECTRONIC-SCAN HORIZON SENSOR
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
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DESCRIPTORS:
7. HORIZON SENSCRS

122. AUTHCRS: MERRITT,E. S.
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¤MICRON CO-2) MEASUREMENTS
SOURCE: ARACON GEOPHYSICS CO.
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DATE: 30 APRIL 1965 20PP
DDC OR NASA NO.
CONTRACT NUMBER N189(188)-58014A
DESCRIPTORS:
4. RADIANCE (EXPERIMENTAL 15 U)
14. METEORCLOGY - SYNOPTIC STUDIES
18. METEORCLOGY SUMMARY STUDIES

123. AUTHCRS: MERRITT,E. S.
CHANG,D. ,
¤ SYNOPTIC STUDIES OF SATELLITE MEASUREMENTS IN THE 15 MICRON
¤CO(2) BAND
SOURCE: ARACON GEOPHYSICS CO.
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DATE: 31 MARCH 1966 48PP
DDC OR NASA NO.
CONTRACT NUMBER N 189(188)-59192A
DESCRIPTORS:
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14. METEORCLOGY - SYNOPTIC STUDIES

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ROGERS,C. W. C. ,
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¤CIRCULATIONS
SOURCE: ARACON GEOPHYSICS CO.
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DATE: 30 OCTOBER 1965 81PP
DDC OR NASA NO.
CONTRACT NUMBER N62306-1584
DESCRIPTORS:
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432. AUTHCRS: MERRITT,E. S.
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¤REGION
SOURCE: ARACON GEOPHYSICS CO.
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DDC OR NASA NO. N63-22441
CONTRACT NUMBER AF 19(628)-320
DESCRIPTORS:
18. METEORCLOGY SUMMARY STUDIES

390. AUTHCRS: MET. ROCKET NET. COMM.(EDITED BY)
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¤VOLUME XLII - FEBRUARY 1965 FIRINGS
SOURCE: U. S. ARMY RESEARCH AND DEVELOPMENT ACTIVITY
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DATE: SEPTEMBER 1965 309PP
DDC OR NASA NO. 474263

DESCRIPTORS:
14. METEORCLOGY - SYNOPTIC STUDIES
15. METEORCLOGY - RAW DATA
18. METEORCLOGY SUMMARY STUDIES

124. AUTHORS: MIERS,B. T.
BEYERS,N. J.
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¤70 KM FOR SELECTED STATIONS
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 3,PP 16-26
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DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
15. METEOROLOGY - RAW DATA

283. AUTHORS: MIKHNEVICH,V. V.
KHVOSTIKOV,I. A.
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SOURCE: BULLETIN OF THE ACADEMY OF SCIENCES OF THE U.S.S.R.
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DATE: 1957 20PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

333. AUTHORS: MILLARD,J. P.
NEEL,C. B.
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¤THE FIRST ORBITING SOLAR OBSERVATORY
SOURCE: AIAA
REPORT NUMBER/DESCRIPTION: 64-317
DATE: 29 JUNE 1964-2 JULY 1964 11PP
DDC OR NASA NO.

DESCRIPTORS:
3. RADIANCE (THEORETICAL OTHER)
6. RADIOMETERS

125. AUTHORS: MILLER,B.
¤ NEW HORIZON SENSORS PLANNED FOR AGENA D
SOURCE: AVIATION WEEK AND SPACE TECHNOLOGY
REPORT NUMBER/DESCRIPTION: VOL. 79, NO. 14, PP 82-86
DATE: 30 SEPTEMBER 1963 05PP
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DESCRIPTORS:
7. HORIZON SENSORS

256. AUTHORS: MILLER,W. L.
GORDON,A. R.
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¤ARISE IN CERTAIN PROBLEMS OF LINEAR HEAT FLOW, ELECTROCHEMICAL
¤DIFFUSION, ETC.
SOURCE: PHYSICAL CHEMISTRY JOURNAL
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DESCRIPTORS:
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287. AUTHORS: MINTZ,Y.
DEAN,G.
¤ OBSERVED MEAN FIELD OF MOTION OF THE ATMOSPHERE
SOURCE: CAMBRIDGE RESEARCH CENTER (AIR FORCE)
REPORT NUMBER/DESCRIPTION: GEOPHYS. RESEARCH PAPERS NO. 17
DATE: AUGUST 1962 65PP
DDC OR NASA NO. 626678
CONTRACT NUMBER AF 19(122)-48
DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

180. AUTHORS: MINZNER,R. A.
□ HIGHER ATMOSPHERIC DENSITIES AND TEMPERATURES DEMANDED BY
□SATELLITE AND RECENT ROCKET MEASUREMENTS
SOURCE: GEOPHYSICS CORP. OF AMERICA
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DATE: 30 APRIL-1 MAY,1959 32PP
DDC OR NASA NO.

DESCRIPTORS:
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181. AUTHORS: MINZNER,R. A.
RIPLEY,W. S. ,
□ ARDC MODEL ATMOSPHERE,1956
SOURCE: CAMBRIDGE RESEARCH CENTER(AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRC-TN-56-204
DATE: DECEMBER 1956 207PP
DDC OR NASA NO. 110233

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

243. AUTHORS: MINZNER,R. A.
CHAMPION,K. S. W. , POND,H. L.
□ ARDC MODEL ATMOSPHERE, 1959
SOURCE: CAMBRIDGE RESEARCH CENTER (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRC-TR-59-267
DATE: AUGUST 1959 142PP
DDC OR NASA NO.

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

266. AUTHORS: MISME,P.
□ MODELS OF THE ATMOSPHERE INFERRED FROM METEOROLOGICAL
□OBSERVATIONS
SOURCE: CAMBRIDGE RESEARCH LAB.(AIR FORCE)
REPORT NUMBER/DESCRIPTION: T-F-63+
DATE: AUGUST 1964 17PP
DDC OR NASA NO. 453043
CONTRACT NUMBER AF 19(628)-3880
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

229. AUTHORS: MITCHELL,A. C. G.
ZEMANSKY,M. W. ,
□ RESONANCE RADIATION AND EXCITED ATOMS
SOURCE: CAMBRIDGE UNIVERSITY PRESS
REPORT NUMBER/DESCRIPTION: 535.3 M69 C.1
DATE: 1961 338PP
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THOMPSON,A. H. ,
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□OBSERVED BY TIROS III OVER THE CARIBBEAN SEA DURING THE PERIOD
□20-21 JULY 1961
SOURCE: TEXAS A AND M RESEARCH FOUNDATION
REPORT NUMBER/DESCRIPTION: AFCRL-64-236
DATE: 1 FEBRUARY 1964 34PP
DDC OR NASA NO. 435823
CONTRACT NUMBER AF 19(604)-8450
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)

126. AUTHORS: MOLLER,F.
□ ON THE INFLUENCE OF CHANGES IN THE CO(2) CONCENTRATION IN AIR
□ON THE RADIATION BALANCE OF THE EARTHS SURFACE AND ON THE
□CLIMATE
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 68 NO. 13,PP 3877-3886
DATE: 1 JULY 1963 10PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)

105. AUTHORS: MORALES,F. W.
□ SECOND-HARMONIC EDGE-TRACKED HORIZON SENSOR, AZIMUTH-SCANNING
□TYPE
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 133-157
DATE: 1965 25PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS

307. AUTHORS: MORGENTHALER,G. W.
FOSDICK,G. E.
□ SELECTION OF LAUNCH VEHICLES, SPACECRAFT, AND MISSIONS FOR
□EXPLORATION OF THE SOLAR SYSTEM
SOURCE: MARTIN COMPANY
REPORT NUMBER/DESCRIPTION: R-64-6
DATE: JUNE 1964 232PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 8-11123 + NAS 8-11057
DESCRIPTORS:
13. MISSION PROFILE
19. LAUNCH VEHICLES AND FACILITIES

406. AUTHORS: MOST,S. L.
□ SUMMARY OF SPACE SYSTEMS STUDIES AND DEVELOPMENT CONTRACTS
SOURCE: AVCO CORP.
REPORT NUMBER/DESCRIPTION:
DATE: JUNE 1964 54PP
DDC OR NASA NO.

DESCRIPTORS:
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19. LAUNCH VEHICLES AND FACILITIES

127. AUTHORS: MUENCH,H. S.
□ DYNAMICS OF THE WINTERTIME STRATOSPHERE CIRCULATION
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 22,PP 349-360
DATE: JULY 1965 12PP
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DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
16. METEOROLOGY - STRATO WARMINGS

128. AUTHORS: MURCRAY,D. G.
MURCRAY,F. H. , WILLIAMS,W. J.
□ BALLOON BORNE INFRARED STUDIES
SOURCE: CAMBRIDGE RESEARCH LABORATORIES (AIR FORCE)
REPORT NUMBER/DESCRIPTION: AFCRL 65-755
DATE: 30 SEPTEMBER 1965 24PP
DDC OR NASA NO.
CONTRACT NUMBER AF19(604)7479
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)
6. RADIOMETERS

286. AUTHORS: MURCRAY, D. G.
MURCRAY, F. H., WILLIAMS, W. J.
□ VARIATION WITH ALTITUDE OF THE TRANSMITTANCE OF THE EARTHS
□ATMOSPHERE WITH GRATING RESOLUTION
SOURCE: UNIVERSITY OF DENVER
REPORT NUMBER/DESCRIPTION: AFCRL-65-854
DATE: NOVEMBER 1965 18PP
DDC OR NASA NO. 626632
CONTRACT NUMBER AF 19(628)-5202
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
4. RADIANCE (EXPERIMENTAL 15 U)

408. AUTHORS: MURCRAY, D. G.
□ RADIANCE OF THE EARTH IN SELECTED WAVELENGTH INTERVALS AS
□OBSERVED FROM HIGH ALTITUDES
SOURCE: UNIVERSITY OF DENVER
REPORT NUMBER/DESCRIPTION: DRI NO. 2149
DATE: 31 MARCH 1964 193PP
DDC OR NASA NO. 437632
CONTRACT NUMBER AF 33(616)-7633
DESCRIPTORS:
5. RADIANCE (EXPERIMENTAL OTHER)

394. AUTHORS: NAKORENKO, N. F.
TOKAR, F. G.
□ CLIMATE OF THE USSR. CLIMATE OF THE FREE ATMOSPHERE. ISSUE 8
SOURCE: AIR FORCE SYSTEMS COMMAND
REPORT NUMBER/DESCRIPTION: FTD-MT-63-339
DATE: 9 FEBRUARY 1965 263PP
DDC OR NASA NO. 613988

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES
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57. AUTHORS: NASA
USAF
CONF. □ PROGRESS OF THE X-15 RESEARCH AIRPLANE PROGRAM
SOURCE: FLIGHT RESEARCH CENTER, EDWARDS AIR FORCE BASE
REPORT NUMBER/DESCRIPTION:
DATE: 7 OCTOBER 1965 139PP
DDC OR NASA NO. NASA SP-90

DESCRIPTORS:
4. RADIANCE (EXPERIMENTAL 15 U)
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6. RADIOMETERS

215. AUTHORS: NASA
□ SIGNIFICANT ACHIEVEMENTS IN PLANETARY ATMOSPHERES, 1958-1964
SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: 1966 59PP
DDC OR NASA NO. SP-98

DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

402. AUTHORS: NASA
□ OFFICE OF SPACE SCIENCE AND APPLICATIONS - PROSPECTUS 1964 -
□A LISTING OF PROGRAM OPPORTUNITIES 1965-1980
SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: 1964 197PP.
DDC OR NASA NO.

DESCRIPTORS:
13. MISSION PROFILE
19. LAUNCH VEHICLES AND FACILITIES

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¤ OFFICE OF SPACE SCIENCE AND APPLICATIONS - PROSPECTUS 1965 -
¤A LISTING OF PROGRAM OPPORTUNITIES - 1966-1985
SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
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DDC CR NASA NO.

DESCRIPTORS:
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405. AUTHCRS: NASA
¤ OFFICE OF SPACE SCIENCE AND APPLICATIONS - APPENDIX B.
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SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: 10 JUNE 1965 315PP
DDC CR NASA NO.

DESCRIPTORS:
11. TRACKING AND DATA ACQUISITION
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18. METEORCLOGY SUMMARY STUDIES
19. LAUNCH VEHICLES AND FACILITIES

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GROOM,N. J. , HATCHER,N. M.
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SOURCE: LANGLEY RESEARCH CENTER
REPORT NUMBER/DESCRIPTION: PP 48-54
DATE: 07PP
DDC CR NASA NO.

DESCRIPTORS:
7. HORIZON SENSCRS

130. AUTHCRS: NEWELL,R. F.
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SOURCE: SCIENTIFIC AMERICAN
REPORT NUMBER/DESCRIPTION:
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DESCRIPTORS:
1. ATMOSPHERIC PHYSICS

224. AUTHCRS: NEWELL,R. F.
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¤IN OZONE AMOUNT
SOURCE: PURE AND APPLIED GEOPHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 59, III, PP 191-206
DATE: 1964 16PP
DDC CR NASA NO.
CONTRACT NUMBER AT(30-1)2241
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
17. METEORCLOGY -STATISTICAL STUDIES
18. METEORCLOGY SUMMARY STUDIES

131. AUTHCRS: NIELSON,R. L.
BODE,D. E. ,
¤ EFFECT OF BACKGROUND RADIATION ON PHOTOCONDUCTIVE INDIUM
¤ANTIMONIDE
SOURCE: SANTA BARBARA RESEARCH CENTER
REPORT NUMBER/DESCRIPTION:
DATE: 03PP
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DESCRIPTORS:
6. RADIOMETERS
7. HORIZON SENSCRS

114. AUTHORS: NORDBERG,W.
BANDEEN,W. R. , WARNECKE,G.
KUNDE,V. ,
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SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: TMX55045
DATE: MAY 1964 57PP
DDC OR NASA NO. N64-28930

DESCRIPTORS:
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14. METEOROLOGY - SYNOPTIC STUDIES
15. METEOROLOGY - RAW DATA
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SOURCE: SYMPOSIUM ON STRATOSPHERIC AND MESOSPHERIC CIRCULATION, BERLIN
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DATE: 1962 19PP
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DATE: JANUARY 1962 11PP
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REPORT NUMBER/DESCRIPTION: EXTERNAL PUB. NO. 505
DATE: 3 JUNE 1958 45PP
DDC OR NASA NO. 264298
CONTRACT NUMBER DA-04-495-ORD 18
DESCRIPTORS:
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9. ATTITUDE CONTROL

399. AUTHORS: OFFICE OF MANNED SPACE FLIGHT
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SOURCE: NASA
REPORT NUMBER/DESCRIPTION:
DATE: JULY 1965 30PP
DDC OR NASA NO.

DESCRIPTORS:
13. MISSION PROFILE
19. LAUNCH VEHICLES AND FACILITIES

400. AUTHORS: OFFICE OF MANNED SPACE FLIGHT
□ APOLLO EXPERIMENTS GUIDE
SOURCE: NASA
REPORT NUMBER/DESCRIPTION: NPC 500-9
DATE: 15 JUNE 1965 50PP
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SOURCE: MIT
REPORT NUMBER/DESCRIPTION: R-492
DATE: MAY 1965 14PP
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PEARSON,F. A.
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DATE: 14 JUNE 1963 95PP
DDC OR NASA NO. 408260
CONTRACT NUMBER AF 04(647)-787
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141. AUTHORS: PALSER,W. E.
□ WIDE-ANGLE, LINEAR-OUTPUT HORIZON SENSOR OPTICAL SYSTEM
SOURCE: APPLIED OPTICS
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DATE: OCTOBER 1963 39PP
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DDC OR NASA NO. 430887
CONTRACT NUMBER AF 19(628)-2946
DESCRIPTORS:
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142. AUTHORS: PETRELLA, A. J.
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DESCRIPTORS:
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234. AUTHORS: PHILCO CORPORATION
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SOURCE: PHILCO CORPORATION
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DATE: 31 JANUARY 1963 58PP
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HILLEARY,D. T. , MORGAN,W. A.
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DDC OR NASA NO.
CONTRACT NUMBER DA-91-591-EUC-3384
DESCRIPTORS:
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DDC OR NASA NO.
CONTRACT NUMBER DA-36-039-SC-78902
DESCRIPTORS:
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DATE: 1965 14PP
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DESCRIPTORS:
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DESCRIPTORS:
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SOURCE: UNIVERSITY OF CHICAGO
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DATE: OCTOBER 1961 27PP
DDC OR NASA NO. 268684
CONTRACT NUMBER SD-71
DESCRIPTORS:
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GERRISH,H. P. ,
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SOURCE: MIAMI, UNIVERSITY OF
REPORT NUMBER/DESCRIPTION:
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DESCRIPTORS:
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DAVISON,G. A.
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SOURCE: PROCEDURES IRIS
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BCGGESS,R. L. , TAEUSCH,D.
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SOURCE:
REPORT NUMBER/DESCRIPTION: PP 326-342
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DESCRIPTORS:
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REPORT NUMBER/DESCRIPTION: PP 55-71
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DESCRIPTORS:
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DATE: 1963
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CONTRACT NUMBER AF 19(604)-7230
DESCRIPTORS:
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DDC CR NASA NO. N64-27910
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CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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157. AUTHORS: STROUD,W. G.
BANDEEN,W. R. , NORDBERG,W.
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REPORT NUMBER/DESCRIPTION: PP 388-407
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16. METEOROLOGY - STRATO WARMINGS

161. AUTHCRS: THOMAS,J. R.
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SOURCE: PROCEDURES IRIS
REPORT NUMBER/DESCRIPTION: VOL. 9, NO. 1, PP 141-154
DATE: JANUARY 1964 14PP
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DESCRIPTORS:
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CRONIN,J. C. , KERR, JR.,R. E.
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SOURCE: AEROMETRIC RESEARCH, INC.
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CONTRACT NUMBER N18957542A
DESCRIPTORS:
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DDC OR NASA NO. 602936
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DESCRIPTORS:
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REPORT NUMBER/DESCRIPTION: 629.13338 1135.6 PT I
DATE: 1965 191PP
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□TELEVISION CLOUD PHOTOGRAPHY PART 2
SOURCE: U. S. WEATHER BUREAU
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□TELEVISION CLOUD PHOTOGRAPHY PART 3
SOURCE: U. S. WEATHER BUREAU
REPORT NUMBER/DESCRIPTION: 629.13338 U35.6 PT III
DATE: 1965 179PP
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17. METEOROLOGY -STATISTICAL STUDIES
18. METEOROLOGY SUMMARY STUDIES

281. AUTHORS: VANDENKERCKHOVE,J.
RENARD,M.
□ ATTITUDE RECONSTITUTION THROUGH CONICAL HORIZON SCANNING
SOURCE: EUROPEAN SPACE TECHNOLOGY CENTRE
REPORT NUMBER/DESCRIPTION:
DATE: OCTOBER 1964 47PP
DDC OR NASA NO. N65-25365

DESCRIPTORS:
7. HORIZON SENSORS
9. ATTITUDE CONTROL

165. AUTHORS: WAGNER,N. K.
□ THEORETICAL ACCURACY OF A METEOROLOGICAL ROCKETSONDE THERMISTOR
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 3,PP 461-469
DATE: AUGUST 1964 09PP
DDC OR NASA NO.

DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

294. AUTHORS:
HARAGAN,D. R.
GERHARDT,J. R.
WAGNER,N. K.
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□QUARTERLY TECHNICAL REPORT NO. 4
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 APRIL 1961 - 30 JUNE 1961 62PP
DDC OR NASA NO. 479080
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

295. AUTHORS:
HARAGAN,D. R.
GERHARDT,J. R.
WAGNER,N. K.
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□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM -
□QUARTERLY TECHNICAL REPORT NO. 5
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JULY 1961 - 30 SEPTEMBER 1961 45PP
DDC OR NASA NO. 479081
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
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297. AUTHORS:
HARAGAN,D. R.
WAGNER,N. K.
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□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM -
□QUARTERLY TECHNICAL REPORT NO. 7
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JANUARY 1962-31 MARCH 1962 68PP
DDC OR NASA NO. 479083
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

299. AUTHORS:
HARAGAN,D. R.
WAGNER,N. K.
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SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 JULY 1962-30 SEPTEMBER 1962 34PP
DDC OR NASA NO. 479085
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

300. AUTHORS:
HARAGAN,D. R.
WAGNER,N. K.
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□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM -
□QUARTERLY TECHNICAL REPORT NO. 10
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 OCTOBER 1962-31 DECEMBER 1962 24PP
DDC OR NASA NO. 479086
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

307. AUTHORS:
HARAGAN,D. R.
WAGNER,N. K.
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□ WIND AND TEMPERATURE IN THE ATMOSPHERE BETWEEN 30 AND 80 KM -
□QUARTERLY TECHNICAL REPORT NO. 12
SOURCE: UNIVERSITY OF TEXAS
REPORT NUMBER/DESCRIPTION:
DATE: 1 APRIL 1963-30 JUNE 1963 10PP
DDC OR NASA NO. 479088
CONTRACT NUMBER DA-23-072-ORD-1564
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

166. AUTHORS: WARK,D. Q.
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¤SATELLITES
SOURCE: GEOPHYSICAL RESEARCH JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 66,NO. 1
DATE: JANUARY 1961
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DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
2. RADIANCE (THEORETICAL 15 U)
18. METEOROLOGY SUMMARY STUDIES

167. AUTHORS: WARK,D. Q.
ALISHOUSE,J. , YAMAMOTO,G.
¤ CALCULATIONS OF THE EARTHS SPECTRAL RADIANCE FOR LARGE ZENITH
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SOURCE: U. S. WEATHER BUREAU
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DATE: OCTOBER 1963 45PP
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2. RADIANCE (THEORETICAL 15 U)
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18. METEOROLOGY SUMMARY STUDIES

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ALISHOUSE,J. , YAMAMOTO,G.
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¤THE EARTH
SOURCE: APPLIED OPTICS
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YAMAMOTO,G. , LIENESCH,J. H.
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¤FROM METEOROLOGICAL SATELLITES
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 19, NO. 5, PP 369-384
DATE: SEPTEMBER 1962 16PP
DDC OR NASA NO.

DESCRIPTORS:
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3. RADIANCE (THEORETICAL OTHER)

371. AUTHORS: WARK,D. Q.
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SOURCE: TORQUES AND ATTITUDE SENSING IN EARTH SATELLITES(ED. BY SINGER)
REPORT NUMBER/DESCRIPTION: PP 207-220
DATE: 1964
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DESCRIPTORS:
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FLEMING,H. E.
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SOURCE: MONTHLY WEATHER REVIEW
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18. METEOROLOGY SUMMARY STUDIES

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SHENK,W.
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SOURCE: ANNUAL MEETING OF AMERICAN METEOROLOGICAL SOC., DENVER,COLORADO
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18. METEOROLOGY SUMMARY STUDIES

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STINSON,J. R.
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SOURCE: NAVAL WEATHER RESEARCH FACILITY
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DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

169. AUTHORS: WEBB,W. L.
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SOURCE: ASTRONAUTICS AND AERONAUTICS
REPORT NUMBER/DESCRIPTION: VOL. 2,PP 62-68
DATE: MARCH 1964 07PP
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DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES

430. AUTHORS: WEBB,W. L.
¤ STRATOSPHERIC SOLAR RESPONSE
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 21, NO. 6, PP 582-591
DATE: NOVEMBER 1964 10PP
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DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

102. AUTHORS: WEINER,S.
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SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 15-27
DATE: 1965 13PP
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DESCRIPTORS:
6. RADIOMETERS
7. HORIZON SENSORS

439. AUTHORS: WEXLER,R.
□ INTERPRETATION OF SATELLITE OBSERVATIONS OF INFRARED RADIATION
SOURCE: ARACON GEOPHYSICS CO.
REPORT NUMBER/DESCRIPTION: SR NO. 1
DATE: 1961
DDC OR NASA NO.
CONTRACT NUMBER AF 19(604)-5968
DESCRIPTORS:
18. METEOROLOGY SUMMARY STUDIES

213. AUTHORS: WIDGER JR.,W. K.
□ POSSIBLE APPROACH TO CROSS-TRACK RADIOMETRIC SCANNING FROM A
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SOURCE: SPACECRAFT AND ROCKETS JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 1,NO. 4, PP 427-429
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6. RADIOMETERS
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183. AUTHORS: WIDGER,W. K.
BARNES,J. C. , MERRITT,F. S.
SMITH,R. B. ,
□ METEOROLOGICAL INTERPRETATION OF NIMBUS HIGH RESOLUTION
□INFRARED (HRIR) DATA
SOURCE: ALLIED RESEARCH ASSOCIATES, INC.
REPORT NUMBER/DESCRIPTION:
DATE: JANUARY 1966 150PP
DDC OR NASA NO. CR-352
CONTRACT NUMBER NAS 5-9554
DESCRIPTORS:
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14. METEOROLOGY - SYNOPTIC STUDIES
18. METEOROLOGY SUMMARY STUDIES

285. AUTHORS: WILCOX,J. C.
□ SELF-CONTAINED ORBITAL NAVIGATION SYSTEMS WITH CORRELATED
□MEASUREMENT ERRORS
SOURCE: AIAA/ION GUIDANCE AND CONTROL CONFERENCE
REPORT NUMBER/DESCRIPTION: PP 231-247
DATE: 16-18 AUGUST 1965 17PP
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DESCRIPTORS:
7. HORIZON SENSORS
8. ATT MEASMT (EXCL HORIZON SENSRS)
9. ATTITUDE CONTROL

312. AUTHORS: WILKINS,G. A.
HOYEM,J. A. ,
□ TERRESTRIAL NIGHT HORIZON AND SKY - 4.3 MICRON RADIANCE DATA
□GENERATED BY THE HITAB-TRIS EXPERIMENTS
SOURCE: U. S. NAVAL ORDNANCE TEST STATION
REPORT NUMBER/DESCRIPTION: NAVWEPS 8552
DATE: JUNE 1964 18PP
DDC OR NASA NO. 446436

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
5. RADIANCE (EXPERIMENTAL OTHER)

170. AUTHORS: WILSON,C. V.
GODSON,W. L. ,
□ STRUCTURE OF THE ARCTIC WINTER STRATOSPHERE OVER A 10-YR PERIOD
SOURCE: ROYAL METEOROLOGICAL SOCIETY QUARTERLY JOURNAL
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DATE: 1963 20PP
DDC OR NASA NO.
CONTRACT NUMBER AF 19(604)-8431
DESCRIPTORS:
14. METEOROLOGY - SYNOPTIC STUDIES
16. METEOROLOGY - STRATO WARMINGS
18. METEOROLOGY SUMMARY STUDIES

126. AUTHORS: WINSTON, J. S.
COMMENTS ON -CLOUD HEIGHTS AND NIGHTTIME CLOUD COVER FROM TIROS RADIATION DATA-
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 22, PP 333-338
DATE: MAY 1965 6PP
DDC OR NASA NO.

DESCRIPTORS:
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14. METEOROLOGY - SYNOPTIC STUDIES
17. METEOROLOGY -STATISTICAL STUDIES

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VIBRATIONAL RELAXATION IN CARBON DIOXIDE. II
SOURCE: CHEMICAL PHYSICS JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 37, NO. 3, PP 655-661
DATE: 1 AUGUST 1962 7PP
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DESCRIPTORS:
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171. AUTHORS: WOESTMAN, J. W.
EARTH RADIATION MODEL FOR INFRARED HORIZON SENSOR APPLICATIONS
SOURCE: INFRARED PHYSICS
REPORT NUMBER/DESCRIPTION: VOL. 3, PP 93-105
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3. RADIANCE (THEORETICAL OTHER)
18. METEOROLOGY SUMMARY STUDIES

173. AUTHORS: WOOD, C. P.
SPREEN, W. C.
INVESTIGATION OF THE RELATION AMONG SOME OF THE STATISTICS FOR UPPER-AIR PRESSURE, TEMPERATURE AND DENSITY
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 2, PP 292-297
DATE: APRIL 1963 06PP
DDC OR NASA NO.

DESCRIPTORS:
17. METEOROLOGY -STATISTICAL STUDIES

172. AUTHORS: WOOD, T. F.
GREAVES, J. R. , JONES, III, C. R.
ARACON PHOTOGRAMMETRIC ATTITUDE SYSTEM DESCRIPTION
SOURCE: GODDARD SPACE FLIGHT CENTER
REPORT NUMBER/DESCRIPTION: OGP-11
DATE: JANUARY 1966 88PP
DDC OR NASA NO.
CONTRACT NUMBER NAS 5-3953
DESCRIPTORS:
8. ATT MEASMT (EXCL HORIZON SENSRS)
21. DATA REDUCTION

217. AUTHORS: WORKING GROUP ON INFRARED BACKGROUNDS
INFRARED TARGET AND BACKGROUND RADIOMETRIC MEASUREMENTS
SOURCE: UNIVERSITY OF MICHIGAN
REPORT NUMBER/DESCRIPTION: 2389-64-T
DATE: JANUARY 1962 43PP
DDC OR NASA NO.
CONTRACT NUMBER NONR 1224(12)
DESCRIPTORS:
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2. RADIANCE (THEORETICAL 15 U)
3. RADIANCE (THEORETICAL OTHER)
6. RADIOMETERS
7. HORIZON SENSORS

342. AUTHORS: WORMSER,E. M.
ARCK,M. H.
□ INFRARED NAVIGATION SENSORS FOR SPACE VEHICLES
SOURCE: ACADEMIC PRESS
REPORT NUMBER/DESCRIPTION: VOL. 8, PP 443-454
DATE: 1962 12PP
DDC OR NASA NO.

DESCRIPTORS:
7. HORIZON SENSORS

364. AUTHORS: WYATT,P. J.
STULL,V. R. , PLASS,G. N.
□ INFRARED TRANSMISSION STUDIES-FINAL REPORT: VOLUME II, THE
□INFRARED ABSORPTION OF WATER VAPOR
SOURCE: FORD MOTOR CO.
REPORT NUMBER/DESCRIPTION: SSD-TDR-62-127-VOLUME II
DATE: 20 SEPTEMBER 1962 249PP
DDC OR NASA NO. 297458
CONTRACT NUMBER AF 04(695)-96
DESCRIPTORS:
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262. AUTHORS: YAMAMOTO,G.
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□VAPOR, CARBON DIOXIDE AND MOLECULAR OXYGEN.
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 19, NO. 2, PP 182-188
DATE: MARCH 1962 7PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

261. AUTHORS: YOUNG,C.
EPSTEIN,E. S.
□ ATOMIC OXYGEN IN THE WINTER MESOSPHERE
SOURCE: ATMOSPHERIC SCIENCES JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 19, NO. 6, PP 435-443
DATE: NOVEMBER 1962 9PP
DDC OR NASA NO.

DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
18. METEOROLOGY SUMMARY STUDIES

174. AUTHORS: YOUNG,M. J.
□ COMPARISON OF METHODS FOR DETERMINING PROBABLE IMPACT AREAS IN
□PLANNING SHORT RANGE INSTRUMENTED BALLOON FLIGHTS
SOURCE: APPLIED METEOROLOGY JOURNAL
REPORT NUMBER/DESCRIPTION: VOL. 1,PP 531-536
DATE: DECEMBER 1962 06PP
DDC OR NASA NO.

DESCRIPTORS:
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18. METEOROLOGY SUMMARY STUDIES

175. AUTHORS: ZACHOR,A. S.
PERSKY,M. J. ,
□ INTERFEROMETRIC OBSERVATIONS OF ATMOSPHERIC RADIATION;
□COMPARISON TO THEORETICAL PREDICTIONS
SOURCE: PROCEDURES IRIS
REPORT NUMBER/DESCRIPTION: VOL. 9, NO. 1, PP 97-101
DATE: JANUARY 1964 5PP
DDC OR NASA NO.

DESCRIPTORS:
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4ö9. AUTHORS: ZDUNKOWSKI,W.
HENDERSON,D. , HALES,J. V.
ɑ INFLUENCE OF HAZE ON INFRARED RADIATION MEASUREMENTS DETECTED
ɑBY SPACE VEHICLES
SOURCE: INTERMOUNTAIN WEATHER, INC.
REPORT NUMBER/DESCRIPTION:
DATE: JULY 1964 68PP
DDC OR NASA NO. 605688
CONTRACT NUMBER CWB-10648
DESCRIPTORS:
1. ATMOSPHERIC PHYSICS
3. RADIANCE (THEORETICAL OTHER)

103. AUTHORS: ZIOLKOWSKI,A.
ɑ HORIZON SIMULATORS FOR SENSOR TESTING
SOURCE: PROC. FIRST SYM.-INFRARED SENSORS FOR SPACECRAFT GUID. + CONTROL
REPORT NUMBER/DESCRIPTION: PP 35-53
DATE: 1965 19PP
DDC OR NASA NO.
DESCRIPTORS:
7. HORIZON SENSORS